AFIT/GIM/LAL/99S-3

POLLUTION PREVENTION COST SAVINGS
USING SUPPLY CHAIN REENGINEERING

THESIS

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THESIS

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G. Scott Webb

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Abstract

Supply chain management was explored as a tool to prevent hazardous waste and reduce operating costs. Previous research had shown that pollution prevention (P2) measures were often costly and no expectation of cost savings could be realized. The reengineering of the Air Force hazardous material supply chain brought about by the Hazardous Material Pharmacy Program was tested to evaluate if hazardous waste had been precluded in this effort and if costs had been reduced.

To date, no research had explored the use of supply chain management as a source reducer of hazardous waste and cost reduction. Consequently, little was known or understood of the effects that the use of this management system would have on preventing pollution. This thesis examined whether or not a reengineering was accomplished, if the reengineering resulted in reduced hazardous waste and if the reengineering reduced inventory costs. The results of the study show that supply chain reengineering did occur in the Air Force hazardous material supply chain, that the reengineering did reduce hazardous waste, and that reengineering did reduce costs.

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I. INTRODUCTION

1.1 Background

Two of today's prevalent business themes are environmental management and logistics management. Significant money and time has been invested by industry in environmental programs with goals of minimizing fines associated with the noncompliance of environmental laws and cleaning up past environmental mistakes. However, these environmental programs are usually implemented with no expectation of saving money.

At the same time, companies have recognized that effective logistics systems can significantly reduce the costs a company imposes on itself. Significant effort has been spent designing efficient logistics systems to decrease costs. By managing the transportation and warehousing of inventory, companies have been able to dramatically decrease operating costs. Some have suggested it is plausible to assume that if positive environmental management using cost efficient logistics was achieved, it could lead to cost efficient environmental systems (Wu and Dunn, 1994: Browne and Allen, 1997).

1.2 Supply Chain Management

Adding to the possibility of this idea of logistics being able to help in the management of the environment is a new realm of management called Supply Chain

Management. This new field looks at the integration of information, warehousing, distribution and any other process that changes the value of a product. Supply Chain Management (SCM) has revolutionized industry by looking at the functional activity (often called functional silos) each product goes through during its life cycle. To understand how SCM would lead to a cost efficient, pollution preventing logistics system, it is first necessary to define supply chain management and then understand how supply chain management is implemented.

Until recently, it was thought that SCM was a synonym for logistics management. However, recent research by Cooper, Lambert and Pagh (1997 and 1998) has used extensive probing of supply chain management research and business practices to define SCM. They concluded that supply chain management can best be conceptualized by three elements: "the business processes, the management components, and the structure of the chain" (Cooper, Lambert and Pagh, 1997: 9) These elements included logistics but were not limited to logistics. The management of a supply chain was much broader as it encompassed all functions that gave value to a product. The three specific elements Cooper, Lambert and Pagh suggest are broad categories of these functions.

A final definition was given for supply chain management from their research. This definition was developed by the Global Supply Chain Forum in 1998 and adopted by Cooper, Lambert and Pagh in their 1998 article. "Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" (Lambert, Cooper and Pagh, 1998: 1). This definition acted as a paradigm

to describe the Air Force reengineering of the hazardous material supply chain in this thesis.

Reengineering of the supply chain would mean SCM had been implemented by the Air Force. However, the implementation and practice of SCM is also an elusive concept. In fact, Lambert, Cooper and Pagh (1998) suggest that most business processes are part of a supply chain, but management of a supply chain is difficult to ascertain. Their three elements previously discussed are used in this thesis as a framework for exploring the hazardous material supply chain. In addition, they suggest three key decisions each supply chain manager needs to address:

1) "Who are the key supply chain members with whom to link processes?
2) What processes should be linked with each of these key supply chain members?
3) What level of integration and management should be applied for each process link?" (Lambert, Cooper and Pagh, 1998: 4)

By managing not just one part of a product's life cycle but instead the product's entire life cycle, SCM could provide system-wide cost savings and other benefits. This thesis looks at the use of these paradigms to first define the supply chain of the Air Force's hazardous materials and then explores whether or not management of this supply chain has led to decreased costs and waste.

1.3 The Hazardous Materials Pharmacy

So how did SCM influence pollution prevention (P2) in the Air Force? The Air Force's mandated management of hazardous materials under Executive Order 12856 (Clinton, 1994) may have led to the creation of a program that not only prevented pollution but also reengineered an entire supply chain.

The implementation of the Hazardous Material Management Program (HMMP), established in 1994, reengineered HazMat inventories on not only a retail level but also throughout the entire Air Force HazMat supply chain. Because of the visibility that this executive order required of HazMat inventory, the entire chain of supply of hazardous materials within the Air Force had to be changed. The reengineering of this inventory has led to claims of both reduced inventory levels and reduced hazardous waste quantities (AFCEE 18402, 1998: 3). It appears that the Air Force has set a benchmark for both environmental management and inventory management.

The success of this program appears to be due to a logistics program effectively rationing the use and amount of use of hazardous materials at Air Force Bases. This more efficient use appears to have lead Air Force Bases to reduce the total amount of hazardous waste they produce with these hazardous materials. In short, it appears the Air Force has successfully not only used supply chain reengineering to reduce holding costs of hazardous materials but also has used supply chain management to achieve P2.

1.4 Problem Statement and Hypothesis One

This research presupposes a supply chain reengineering was done because of the Hazardous Materials Pharmacy Program. However, it is obvious from reviewing literature of the genesis of the Hazard Materials Pharmacy that reengineering the supply chain was not the purpose of the Hazard Materials program. It was actually established to comply with an executive order, not to restructure a supply chain.

To address the research objective, this thesis first must answer an underlying but vital question. Did the Hazardous Materials Pharmacy reengineer the supply chain of Air Force Hazardous Materials?

This question led to the generation of a hypothesis to guide the research to be accomplished.

Hypothesis one: The hazardous materials pharmacy program reengineered the Air Force's supply chain of Hazardous Materials.

1.5 Problem Statement and Hypothesis Two

There remains, however, a significant problem with a supposition stating that reengineering a supply chain can reduce hazardous waste. The problem is that supply chain management has been established as a good reducer of safety stocks, costs and errant information (Lee and Padmanabhan, 1997), but it has never been established as a good environmental management tool. In fact, it is just recently that logistics managers were identified as having a good strategic position for managing environmental activities (Browne and Allen, 1997: 13). The second problem that this thesis will address is

whether or not managing a supply chain can successfully reduce hazardous waste at the source of the pollution.

Since this problem is central to the research it led to the second hypothesis.

Hypothesis two: Reengineering of the hazardous materials supply chain reduced the amount of hazardous waste the Air Force produced.

1.6 Problem Statement Three and Hypothesis Three

Finally, it is also a problem to state that costs can be reduced in an environmental endeavor. Generally, environmental cost savings have been measured in fine avoidance and public good will, not in actual cost savings due to efficiencies. In fact, the EPA recently published findings of several attempts at cost-cutting environmental programs that have failed or were not instituted because they did not present a good rate of return on the companies initial investment (Boyd, 1998: 2). Generally stated, "The Traditional view in management circles about the relationship between the environment and business can best be summed up as pollution pays, P2 doesn't" (Gallarotti, 1995).

The last problem addressed in this research is then, whether or not a specific P2 measure, reengineering of a hazardous material supply chain, can actually reduce operating costs. This research will not consider public goodwill or fine avoidance as operating costs, but will instead analyze those costs associated with any inventory, such as holding costs, ordering costs and transport costs in the hope of showing that P2 can indeed be considered cost efficient.

The final and central question of this thesis is can supply chain reengineering be used as cost effective environmental management tool? Again, because this question is central to the research it can be tested through this study's third hypothesis.

Hypothesis three: The reengineering of the Air Force Hazardous Materials Supply Chain decreased the costs associated with the HazMat inventory.

1.7 Research Focus

Although the focus of this research appears to be on cost savings and waste reduction, it is important to realize the actual focus is on using supply chain management as a cost effective way to reduce hazardous materials. Since the reduction of hazardous waste and the cost savings both provide insight into the effects of supply chain management, they provide the necessary data to help support the overall focus. This research attempts to introduce to Logistics Managers and Environmental Managers the importance of integrating supply chain management into environmental planning. It also reinforces the idea that Logistics Managers have a unique position to influence the environmental footprint of companies (see Wu and Dunn, 1994).

1.8 Assumptions/Limitations

There are several assumptions that must be stated in order to implement this research. The first major assumption is that the Air Force holding cost percentage used is indeed the holding costs for hazardous materials. Since many hazardous materials have a shelf life, they are actually perishable in nature, and many perishable items have a non-linear holding cost (Giri and Chaudhuri, 1998: 468). However the Air Force holding cost

percentage is actually treated as a linear holding cost and doesn't take account for the perishable nature of hazardous materials.

In addition to the assumption of linear holding costs is the assumption that costs will not include improved public image, avoided non-compliance fines, increased profitability or other intangible resources (Russo and Fouts, 1997: 539-540). Although this may appear to assume away many of the cost savings that P2 traditionally provides, these constructs introduce variables into the research that, although accepted, are not readily allocated to total costs (White and Savage, 1993). The research will attempt to show that SCM reduced costs commonly associated with any inventory (Lambert and Stock 1993: 359-391). This limitation may also provide a strength as it will attempt to show actual cost savings rather than intangible costs savings. However, it must be realized that overall cost savings may thus be understated.

Another limitation of the research is that it assumes that the decline in demand of hazardous materials was due to the reengineering of the supply chain and not due to other factors. Since many factors may have influenced demand, this assumption allows for the research to focus on the reductions without doing effects test and other information gathering to uncover confounds. This research is exploratory, and as exploratory research narrowed its scope to only concentrate on the core research questions. Analysis of other variables influencing the supply chain is outside the scope of the research

Additional limitations include those in the hazardous waste area. Since it is often difficult to identify when hazardous materials were purchased that generated specific hazardous waste, waste may be accumulated through time leading to a misrepresentation

of the relationship from hazardous materials to waste. Although this is a definite limitation of the research, as the HazMat Pharmacy program matures and reaches a steady state, and with the flushing out of hazardous waste spawned by Biannual inspections (the Air Force Environmental Compliance and Management Program) it is assumed that hazardous waste generation is fairly recent.

The multifaceted Air Force mission was too complex to study in its entirety. As a result the research was limited to only Air Mobility Command bases to help narrow both the extent of the research and also the scope of the research. Narrowing the research in this manner made the data and the results more manageable. Since preparing aircraft for takeoffs most closely resembles an industrial environment, the applicability of this research will most closely resemble an industrial environment. However, the research intentionally excluded the few bases that had research oriented and non-flying missions due to the greater diversity of their use and application of hazardous materials.

1.9 Implications

This research will attempt to discover if the supply chain reengineering of the Air Force hazardous materials inventory did indeed provide both cost savings and P2. Although much anecdotal and base level evidence appears to support the idea that hazardous waste has been reduced and that costs have been reduced, no real study of the reengineering has been done. This research should substantiate the notion that the Air Force has in fact reduced hazardous wastes and reduced costs.

In addition, no studies regarding the use of supply chain management, as a source reducer of pollution have been identified. This is an important finding as it gives both environmental managers and logistics managers an opportunity to use a new tool to not only reduce hazardous wastes, but also save money. This research should also lead to the ability to optimize the supply chain of hazardous materials while leveraging waste against cost. With the advent of President Clinton's call for sustainable development and for reduced use of environmental pollutants, a tool to accomplish source reduction while saving money may move companies and government agencies from strategy based on fine avoidance to voluntary environmental compliance.

II. LITERATURE REVIEW

The research will review current literature in five main areas: P2, the Air Force Hazardous Material Pharmacy, supply-chain management, reengineering and "Green Logistics." The research will explore in each area the defining characteristics of each construct as well as how each of these sections relate to the thesis' overall purpose of showing that cost effective P2 can be accomplished by reengineering a hazardous materials supply chain.

It is primarily important to understand how reducing the Air Force hazardous material inventory can accomplish both P2 and cost reduction. To do so the research will first define P2 and then discuss the environment of P2 in the Department of Defense today. After this discussion of P2 a literature review of the how the Hazardous Materials Pharmacy was a P2 measure was discussed. Then, supply chain management and its relationship to cost reduction will be discussed in terms of how the Hazard Materials Pharmacy can indeed be a supply chain reengineering. Reengineering management of supply chains will also be discussed. Finally, a review of current literature discussing the environmental and cost advantages of having a system that is both lean and environmental will be discussed. This review will be used to show the possibility of using environmentally sound strategy, policy and business practices to gain industrial cost savings. The overall objective of this literature review is to determine if there is

literature to support the hypothesis that supply chain management can indeed reduce pollution while cutting costs.

2.1 Pollution Prevention

To begin, P2 can be simply defined as reducing the manufacture of pollution through managing the entire life cycle of the pollutant. In other words, P2 is managing the materials that cause waste at their source so that waste is precluded. Even though this concept may seem intuitive, it has not been readily used until recently. The environmental protection agency recommended in 1994 that all Federal agencies "Make a written commitment to utilize P2 through source reduction, where practicable, as the *primary means* of achieving and maintaining compliance with all applicable Federal, State and local environmental requirements" (EPA, 1994: 15, italics added).

The EPA previously declared that source reduction is the key to P2 and further defined what exactly constitutes source reduction in a 1992 memo. It stated "The term (source reduction) includes: equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control" (EPA, 1992: npg).

P2 is accomplished in many ways including new technology, product redesign, and reverse logistics. However, recently it has been suggested that P2 can be accomplished through better management of hazardous material information. As a result, many companies have included computerized tracking of hazardous materials as a P2 resource.

Because of the effectiveness of these computerized programs in reducing hazardous waste "the Department of Ecology (in the state of Washington) changed its regulations to allow sites the option of implementing an environmental management system instead of submitting a P2 plan" (Barron, 1998: 57).

Barron also recognizes in this article that the computerized tracking system the Air Force used at Fairchild Air Force Base's Hazard Materials Pharmacy is indeed a P2 measure. This is the same environmental tracking system that all base level hazardous material pharmacies use, thus identifying the Air Force Hazardous Material Pharmacy information systems as a P2 measure.

2.2 The Hazardous Material Pharmacy Program

Since the HMMP has been identified as a P2 initiative, where did it originate, what is its purpose and how does it prevent pollution? The HMMP history begins in the early 1990's when the source reduction of environmental pollutants was on the forefront of legislation. In 1993, President Clinton produced a landmark executive order, 12856, directly aimed at the federal government's pollution produced during this time. In his own words, "federal facilities will set the example for the rest of the country and become the leader in applying P2 to daily operations, purchasing decisions and policies" (Clinton, 1993). President Clinton also gave very specific guidelines and timelines that every federal facility had to comply with to meet this new law. For instance, in the Department of Defense (DoD), reorganization and restructuring of the supply chain to regulate hazardous material use were necessary to comply with this law.

Executive Order 12856 dramatically changed the Air Force's handling of its hazardous material inventory. Hazardous materials, defined as ozone depleting chemicals, "the 17 chemicals deemed most hazardous to the environment by the Environmental Protection Agency and any industrially used chemical known to cause harm to people or the environment" (AFCEE, 1994) were now considered a prime target for source reduction. Federal Standard 313D paragraph 3.2 contains examples of hazardous materials.

This executive order changing the Air Force management had three main purposes:

1. Before this law, the federal government did not have to comply with "Right to know" laws. These laws provided communities consumption data from all industrial users of hazardous materials. EO 12856 made the federal government, the largest users of hazardous materials in the United States, follow these laws.
2. The law ordered the federal government to become a role model in hazardous material source reduction, i.e. buying less of them.
3. The federal government was ordered to reduce the resulting waste streams from hazardous materials (EPA, 1994).

Previous to this EO, the HazMat inventory, excluding its transportation, was handled like any other material within the AF inventory. However, since the introduction of EO 12856, extensive time, effort and money has been spent on the construction of an environmentally safe warehouse, known as the HazMart, to house the hazardous material inventory on Air Force Bases. This mandatory reshelving of HazMat was expensive, but

the costs could not be avoided due to the new requirements, any items considered hazardous had to follow Environmental Protection Agency Laws regarding storage and disposal (EO 12856). The extra costs of this storage became a requirement of handling HazMat.

Additional money was spent on computer bar-coding systems to track hazardous materials and monitor their consumption. Extensive customer profiles and hazardous material usage data were compiled at every Air Force Base by the pharmacies (EPA, 1998). In addition to the new facilities and information systems, the Air Force decided the best means to comply with this executive order was to establish policy and strategy to direct the control of hazardous materials (EPA, 1998).

The policy directed P2 in two important ways. First it included source reduction of hazardous materials through substitution. One of the key tasks of the HMMP was to find suitable non-hazardous or less hazardous substitutes for traditionally used hazardous materials. Because the hazardous material pharmacy works on a pharmacy concept (a user can't get hazardous materials without prior authorization), it also forced users to quickly implement non-hazardous substances (AFCEE, Nov 1998: 8). Substitutions of processes were also recommended, such as using manual deicing of wings instead of using propylene glycol. In its infancy, many hazardous materials with readily available substitutes and easily substituted processes were quickly replaced in the Air Force inventory.

The second key goal of the Hazard Materials Pharmacy policy was to reduce resulting hazardous waste due to hazardous materials with an expired shelf life. Because

the Air Force puts a time limit on the amount of time a hazardous material can stay on the shelf, any hazardous material staying longer than the recommended shelf life becomes hazardous waste (AFI 23:110, 7:3). The Air Force tackled this problem in two ways: First, by following the Pharmacy concept, demand of hazardous materials was reduced to just the people who really needed the materials. Because the necessary paperwork for environmental approval was tedious and the threat of denial of materials possible, only the necessary users of most hazardous materials attempted to procure hazardous materials. For instance, previous to the pharmacy it was not an uncommon occurrence to find spray paint cans with expired shelf-lives containing heavy metals in them in almost every shop on base. In one instance at McChord Air Force Base, an inspection by the researcher of this thesis discovered that the Base Exchange had in its personal use locker over 50 cans of spray paint containing heavy metals that had not been used in over 5 years.

Second and most important for this study, the result of this pharmacy system's stringent rationing of HazMat was smaller inventories. The hazardous materials pharmacy appears to have accomplished its goal of P2 by focusing on the reduction of its inventory (Air Force Instruction 32-7086).

However, the HMMP has problems and its effectiveness has been questioned. Perhaps the biggest problem has been the matrixed organization of the HazMat Pharmacy (AFI 32-7086: 10). Because of this structure, employees in the HazMart reported to three chains of command, the Base Environmental Manager, the Base Bioenvironmental Engineer (Industrial Hygiene) and the Logistics Group (depending on the base, it

sometime reported directly to the Logistics Group Commander and sometimes to the Supply Squadron Commander). This confusing organization led to conflicting goals, often with the "lead" organization getting the final word in the direction of the pharmacy.

The matrixed organizations also did not speak the same language. For example, the environmental management departments usually wanted consumption data broken down into how many pounds of a specific chemical the base used for their environmental reporting. Since many products contain small percentages of hazardous chemicals, base supply could only provide data on the amount of specific line items the base used in certain stock classes or national stock numbers.

Another problem with the hazardous materials pharmacy was the Air Force Environmental Management Information System (AF-EMIS). This computer program was designed to provide consumption data for environmental reports (RCRA), as well as organize approved hazardous material "prescriptions" from the base environmental engineer and barcode and track all hazardous materials. The computer system was problematic at best and often non-functional until 1997. Since then, it has been effective at tracking this information.

Finally, a government credit card, named the IMPAC card, was a problem to the HMMP concept. This presented a threat because the control of the hazardous materials entering base was lost due to consumers being able to use this card to purchase materials directly from the vendor.

Almost all of these threats to the hazardous materials pharmacy have been countered, however, at a smaller degree they all remain viable problems. The government credit

card still remains probably the biggest challenge as many consumers do not know if what they are buying is hazardous, so they bypass the hazardous materials pharmacy. In a final analysis, it appears that the main thing the HMMP provided the Air Force was more efficient use of Hazardous Materials and more realistic demand information concerning hazardous materials.

2.3 Supply Chain Management

One important aspect of the HMMP, leading to a reduction in hazardous material inventory was to place Logistics Managers (Base Supply) in charge of reducing the Hazardous Material inventory, not the environmental manager. Because of their specialized experience in managing inventory, Supply has proven very effective in reducing the AF Hazardous Material inventory. For instance, "Hill AFB reports its hazardous material cell reported $20 million in savings in just two years with this program" (EPA, 1998). It is obvious that one of the reasons the Hazardous Material Pharmacy and similar civilian P2 measures have reduced operating costs is a dramatic decrease in inventory at key locations.

Recently, inventory management has been directed at using real time information to place optimum amounts of inventory at optimum locations and leveraging the inventory costs against transportation cost. These techniques, the logistics part of supply chain management, are now common business practices. In fact, it appears that although it may have been unintentional, the Hazardous Materials Pharmacy appears to be one of the supply chains reengineered to accomplish its inventory reduction goals.

To understand how this was accomplished, it is first necessary to understand how supply chain management works. Basically, supply chain management manages the information, coordination and organizational linkage of inventory from cradle to grave. "The key to understanding this complex management tool is to think of it in terms of the total integration of transportation, warehousing and information flow" (Lee, 1998).

The understanding of SCM leads businesses to a competitive philosophy based on cooperation. SCM implementation relies heavily on everyone in the chain of supply working together to get a product more efficiently and with the greatest added value to a customer. This includes transporters, buyers, middlemen and retailers. Most businesses are eager to include themselves in a supply chain reengineering because "SCM enhances the competitive edge of all 'players' therein" (Berry and others, 1994).

By reengineering the logistics systems within a chain of supply, many strategic goals for a business can be accomplished. It is important to realize that "Supply chain management calls for and in the end depends on strategic decision making" (Houlihan, 1988). A supply chain is structured by the goals of the cooperating companies using information, transportation and inventory as tools to accomplish those goals. Strategy then plays an important role in supply chain management.

The biggest reason most companies have embraced supply chain management, however, is the huge cost savings it generates. For instance, "due to its supply chain reengineering Digital Equipment Corporation (DEC) estimated savings of $167 million in annual manufacturing costs and $200 million in annual logistics costs" (Arntzen and others 1995). The DEC savings were not an isolated incident, as 25 case studies of

different companies have documented the significant cost saving supply chain management supplies (Lee and Khumawala, unpublished). SCM has proved an effective cost management tool and an effective inventory control tool.

So how does a company integrate its supply chain? Scott and Westbrook suggest that "companies must integrate through:

(1) recognising end customer service level requirements;
(2) defining where to position inventories along the supply chain, and how much to stock at each point;
(3) developing appropriate policies and procedures for managing the supply chain as a single entity" (Scott and Westbrook, 1991: 23).

Others have suggested that integrating a supply chain consist mainly of finding the right players to make the supply chain the least costly (Cavinato, 1992).

It is of interest that much of the early work in supply chain management was in the grocery industry and the computer industry (Whiteoak, 1983: King and Phumpiu, 1996: Arntzen and others, 1995). This is due to the fact that it is widely recognized that supply chain management works very well with short life-cycle products. These products have unique characteristics and demand different management than traditional products (Kurawarwala and Matsuo, 1996: 131).

In the end, it appears that reducing hazardous waste and saving money by reengineering the supply chain of Hazardous Materials logically follows the purpose of supply chain management since large success with supply chain management has been realized in short life-cycle products. Regardless of this similarity, it is necessary to show the similarities of supply chain integration and the Hazardous Materials Pharmacy Program.

The similarities between supply chain management and the Air Force Hazardous Material Pharmacy Program are compelling. Three desired outcomes of supply chain management are cost savings, optimized inventory placement or postponement and cooperative data sharing with suppliers.

In the civilian sector, for instance, information sharing led to more effective supply chains. "Wal-Mart recently changed the software in its cash registers to tell Warner-Lambert, their main packaged good supplier, real time information about inventory levels" (Bair and Wilson, 1998).

In the hazardous materials pharmacy, one of the major efforts was to gather consumption data from users of hazardous materials (AFCEE, 1994). The Air Force, by incorporating more accurate data gathering, implemented some supply chain management. The Air Force data gathering has gotten more sophisticated and more accurate as the HMMP has aged. Currently most pharmacies track customer inventory levels using bar codes and the Air Force Environmental Information Management System (AF-EMIS). This computer system tracks up-to-date information on the amount of hazardous material each customer on an AF base is using and when they used it.

Additionally, supply chain management teaches that "inventory has different economic and service impact at different points on the supply chain" (Lee and Billington, 1993). The hazardous materials pharmacy also addressed the best locations to store hazardous materials. Through time the Air Force found the worst place to keep hazardous material inventory was on the consumers shelf. Because customers tended to dramatically overestimate the amount of hazardous materials they needed, they often

bought more than they could use and the hazardous commodities aged into hazardous waste (AFCEE, 1996: 5). "A study conducted by one major command previous to HMMP implementation revealed 11%-18% of their hazardous waste stream was hazardous materials with expired shelf lives" (AFCEE, 1996: 1). This overestimation of demand at the consumer level has been shown in the literature to cause a "bullwhip effect" throughout the supply chain by increasingly distorting demand upstream from the consumer (Lee, Padmanabhan andWhang, 1997). As a result, the bullwhip effect of poorly captured demand causes the wholesale level supplier and retail level supplier to carry much more stock than is needed, leading to waste.

Finally, supply chain management provides cost savings. We have already documented the savings both the hazard materials pharmacy and supply chain management provides to its users. The previous research reviewed revealed that P2 doesn't typically save costs. These finding makes the cost savings of the hazardous materials pharmacy appear to be due to supply chain reengineering.

By putting these three categories of supply chain management together, it seems that some limited sort of supply chain reengineering has influenced the Air Force hazardous material inventory.

2.4 Reengineering

Evidence of reengineering this supply chain is central to this thesis. In order to understand if reengineering has been done, it is first necessary to define reengineering. Reengineering can best be stated as the "radical redesign and restructuring of business

processes" (Hammer, 1990). Some of the principles of reengineering are that managers should organize their reengineering around outcomes, not tasks (Hammer, 1990: 108). Although this may sound like quality management, business process reengineering differs dramatically from traditional total quality management. Total quality management emphasizes incremental restructuring of the company while reengineering emphasizes significant business changes (Cheyunski and Millard, 1998). The initial restructuring of the pharmacy was to reduce the amount of hazardous wastes, reduce the use all hazardous materials and eliminate the use of all ozone depleting chemicals (EPA, 1995). Clearly, the reengineering of this supply chain was done with a radical outcome in mind, not slowly changed tasks.

Additionally, Hammer, 1990, suggests that those who use the output of the process should perform the process. This was accomplished by the Hazard Materials pharmacy giving responsibility for the proper storage and use of hazardous materials to the customers. Customers had to not only justify their use of the product, but also justify how they intended to use the product (Air Force Form 3962: Appendix I).

Another aspect of reengineering is that often information technology drives this business process (Orman, 1998: 187). Indeed an important driver in the reengineering of the supply chain is the use of an extensive database to track the use and the users of HazMat. It appears as though the establishing of the pharmacy again met the criteria for the supply chain having been reengineered.

Other aspects of business process reengineering, which several authors suggest are necessary for reengineering, were accomplished by the Hazard Materials pharmacy to

some degree. However, not all agree that reengineering is an effective way to produce desired results. Jaffe and Scott, 1998, argue that the several flawed assumptions within reengineering alter its results and Geisler established that "Reengineering continues to fail because of unrealistic expectations, a lack of measurable targeted goals, and the creation of an overly optimistic backdrop to the forthcoming changes" (Geisler, 1996: 71).

Many criticize business process reengineering due to the lack of significant change it brings, however reengineering in practice often ignores the precepts reengineering is predicated upon (Geisler, 1996: 73). Many companies have attempted reengineering in part, ignoring the concept that reengineering is a radical redesign. Much of the failure of reengineering can then be addressed through the disconnection between reengineering in theory and reengineering in practice.

The hazardous materials pharmacy appears to represent a wholesale change in the management of hazardous materials. The HMMP appears not to have been an incremental change but a radical change. This thesis will explore if this was indeed a complete change, if the reengineering was based on information management and if the business structure was changed. In short, it will discuss the three aspects of supply chain management discussed by Lambert, Cooper and Pagh (1998): Management, business processes, and structure.

2.5 P2 Pays

Although the review of current literature found no studies conducted to suggest that supply chain management could be used to accomplish pollution prevention (P2), there are articles suggesting environmental programs can indeed lead to cost savings. This review of these articles will attempt to show the common themes between these studies and apply them to the Air Force Hazardous Materials Pharmacy.

Several recent articles have suggested cost savings can be realized with environmental programs. The theme most common in them, however, is discussing the necessary costs that these proposals may incorporate. A common theme is cost avoidance through fine evasion, public perception and other intangible costs (Russo and Fouts, 1997). This traditional view is however being challenged. Miriam Pye (1998) presented several case studies in her 1998 article, showing projects that "not only prevent pollution but also reduce energy and material costs, reduce disposal costs, reduce liability, increase sales, improve product quality, enhance productivity, preserve and increase jobs, and improve working conditions" (Pye, 1998: 54). It appears from initial review that cost savings may indeed be realized through environmental programs such as the hazardous materials pharmacy. However, these cost effective, environmental efforts did not represent reengineered supply chains like this thesis will study.

The thrust of this thesis is on the management of supply chains, not in environmental management. The emphasis of this thesis, therefore, is on using supply chain management to prevent pollution. Inventory control, a subset of SCM, has also been a key point in recent P2 literature. For instance "Operationally, 3P ("P2 pays") moved

toward limiting the generation of waste and reusing residual materials through raw material substitution, end-product substitution, process modification, equipment redesign, recovery, good housekeeping, *inventory control*, segregation and direct recycling" (Gallarotti, 1995: 39).

Browne and Allen (1997: 13) have suggested that "Logistics managers are involved in all aspects of a product's life cycle – from cradle to grave – and understand about designing, not simply for consumption but also for disposal." It appears that inventory control and logistics managers are indeed poised to effect P2. Finally, management may play an important role in reducing hazardous waste. Many businesses have recognized that environmental technology and environmentally friendly strategy play an important role in total cost reduction in a facility (Gallorotti, 1995: Shrivastava, 1995). However, to be fair, combining P2 and cost savings is not generally possible. Several companies have tried, but failed to find ways to make P2 profitable (EPA, 1998). In final analysis, it appeared that achieving both P2 and cost savings is really a remarkable feat.

It has been suggested that "better hazardous materials management ultimately means waste reduction" (Barron, 1998: 57). Considering the costs of hazardous wastes alone, it appears intuitive that money would be saved, however the ultimate consideration for this thesis will be the savings on carrying inventory. Inventory is expensive and counterproductive as "Stuff that sits in inventory does not earn anything. In fact, it ties down expensive money and absorbs time" (Drucker, 1990: 98). In conclusion, this thesis will attempt to show that sufficient evidence exists to suggest that the supply chain of

hazardous materials has been reengineered, the reengineering reduced hazardous waste and money has been saved.

III. METHODS

3.1 Introduction

The methods used to evaluate the three proposed hypotheses are varied. The first hypothesis requires a qualitative examination of data, while the other two hypotheses require a quantitative look at the data. Each section has some common factors that will be discussed in the initial phases of this chapter. The rest of the chapter will discuss the methods necessary to individually evaluate the three hypotheses.

In order to understand the importance of the methods some background information of the original supply chain is required. Of particular importance to this thesis is the structure of the hazardous material supply chain. Clinton and Morash suggest that a flexible supply chain structure allow for business practices that can quickly complement business strategy (Clinton and Morash, 1997: 6). Outlining the structure of this supply chain is important to this thesis to help define the capability of the supply chain.

Understanding the structure is also helpful because it can be used to outline business process and the underlying strategy and policy that shape the chain. The structure also explains assumptions of the research; for example, it is obvious from this figure that this study investigates only that part of the supply chain that is integrated under the Air Force's control. This was necessary to simplify analysis and arrive at results that were meaningful to the Department of Defense. The structure of the chain is included as Figure 1.

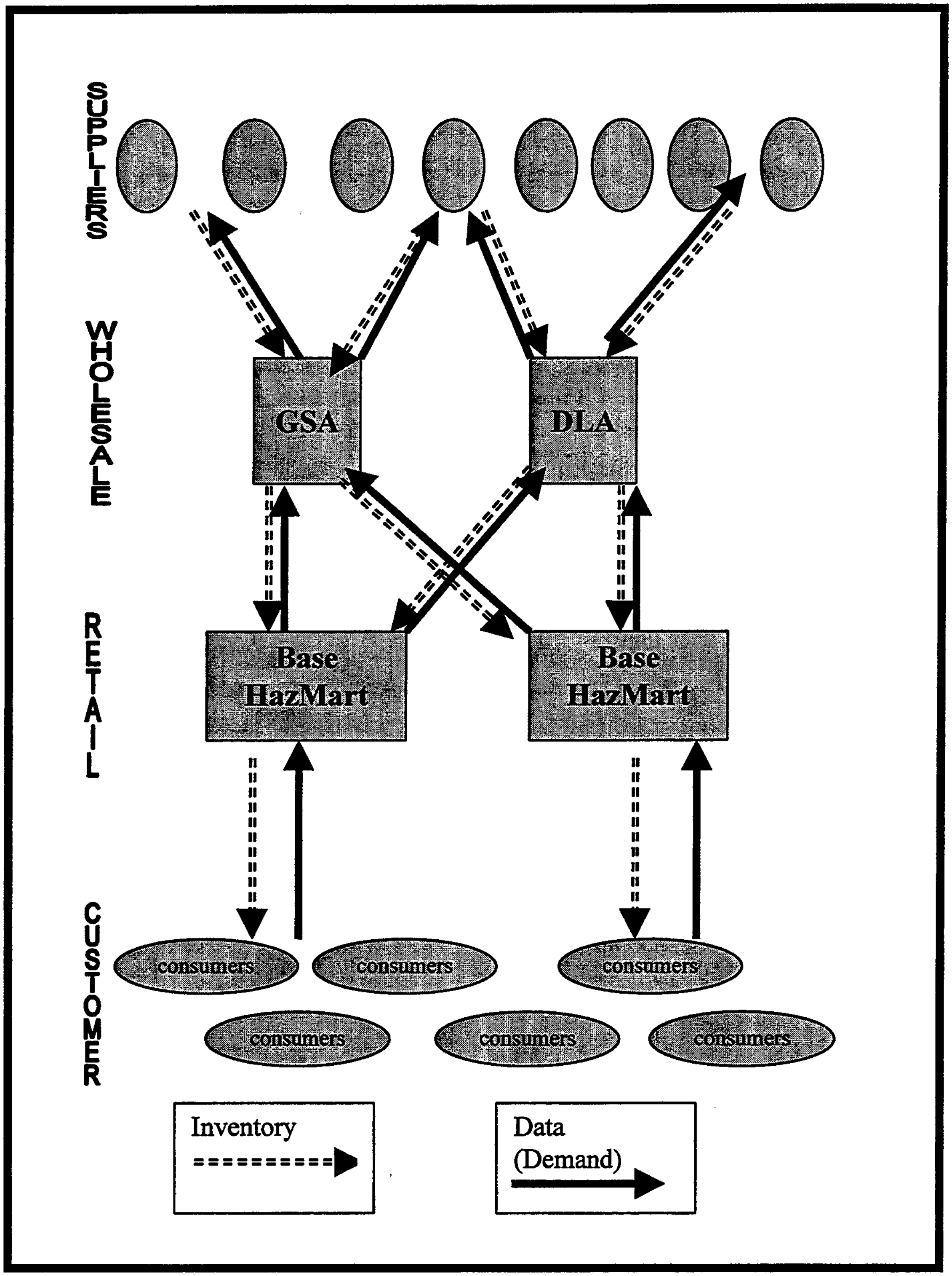

Figure 1. Original Hazardous Materials Supply Chain - 1994

The structure is best described as several civilian suppliers working closely with contracting agents within the Department of Defense to supply hazardous materials to two wholesale level suppliers, Government Services Agency (GSA) and the Defense Logistics Agency (DLA). These wholesalers in turn provide the retail levels throughout the Department of Defense with their hazardous materials, then Air Force retailers (the HazMart) distribute goods to many consumers at each base (see figure 1).

In addition to the structure, it is necessary to explore all three hypotheses proposed by this thesis. The methods to test each of the hypotheses, the data collection techniques and the data preparation are all discussed in detail in this chapter. Since SCM is not just logistics, the methods section also discusses the tests used for each of the SCM aspects suggested by Cooper, and others 1996: structure, management and business processes.

3.2 Hypothesis One

Hypothesis one: The hazardous materials pharmacy program reengineered the Air Force's supply chain of Hazardous Materials.

Structure, business processes and management are all evaluated to test this hypothesis. It has been suggested that qualitative research methods should be used in cases where the breadth of a subject area is being expanded, reengineering of supply chains to reduce hazardous waste fits this category. Qualitative research in this study consisted of soliciting information by electronic mail from various individuals to decipher the Air Force supply chain structure both as it was in 1994 and as it is in 1999.

It also looked at business practices in terms of inventory policy and hazardous materials policy. And finally, it included a review of strategy and policy within the Air Force and department of defense to verify a policy change or a change in the management.

This first test of hypothesis explored whether or not the Hazardous Materials Pharmacy Program did cause a supply chain reengineering. Because many companies have previously claimed reengineering only to be criticized for their implementation of BPR (Jaffe and Scott, 1998), it is important to show that the entire supply chain was reengineered and implementation was not impeded. Data was gained through various means and analysis of the data was done by qualitatively analyzing three central claims found in reengineering literature.

3.2.1 Data Collection. Data was obtained through electronic mail from the Defense Logistics Agency Office of Operations Research and Resource Analysis (Coy, 1999: see Appendix D and Appendix G), McChord Air Force Base (Poling, 1999, Appendix H), Charleston AFB (Barber, 1999: Appendix E), Dover AFB (Price, 1999 Appendix F), the Air Force Logistics Management Agency (Ohnemus, 1999: Appendix B and Appendix C) at Gunter Annex and the Government Services Agency (GSA) Environmental Engineering department (Schroeber, 1999: Appendix I).

The type of data obtained was varied and expansive. GSA data represented the experience of a manager who had been in the GSA environmental affairs office during the reengineering and who was able to describe business processes that were reengineered by the Department of Defense. He was able to summarize not only the processes he

observed but also the outcomes of these observed changes. Information from other sources consist mostly of data concerning the identity of vendors for the studied line numbers and who supplied certain line items at different links in the supply chain.

Additionally, since supply chain management is not simply logistics but also business practices and management, data also was additionally found by procuring Air Force and Department of Defense policy and strategy documents used between 1994 and 1999. This data was found by searching Department of Defense databases, websites and libraries regarding hazardous materials, inventory management and environmental management.

3.2.2 Method of Analysis. To begin the analysis, Hammer, 1968, described "Re-engineering" as the radical redesign and restructuring of business processes. The method to explore reengineering of the structure was to analyze the business processes throughout the supply chain both before and after the supposed reengineering took place. This was accomplished by inspection of the structure of the two chains. By analyzing the chain structure in 1994 against the structure for 1999, a comparison of the structure change between the two years was accomplished. This analysis included two test of hypothesis concerning key inventory measures: demand levels and safety stock levels. The demand level is an estimated number describing the units that could be in the entire system at any time. It includes the amount of inventory that could be on-hand, in a shipping pipeline or in repair (with reparable items) (AFI 23-110, Volume 2, Part 2, chapter 19). Safety stock items are those items kept in stock to buffer against uncertainty in demand (DLAM

4140.2, volume 2, part I, chapter 56). These tests were done to determine if the structure of the inventory within the supply chain had significantly changed.

The analysis throughout this thesis views the supply chain as an integrated supply chain. The is different from what has traditionally been measured, since the segregated supply chain views the supply chain as separate links pieced together into a system. In other words, a segregated level would look at DLA, GSA, Dover AFB and Charleston AFB as separate entities. The analysis would then treat the same line items at different locations as different data points. This gives an overall view of the supply chain as individual links joined together rather than as an integrated system. The integrated analysis treats the sum of all the measures of one line item as one data point. In other words, it looks at the supply chain as one system rather than as independent links. An integrated approach is used in this thesis as a more appropriate supply chain measure since it allows a system wide analysis of the supply chain, rather than a localized analysis of the segregated view.

Both the safety-stock levels and demand levels were tested for decline by using a test of proportions. The test of proportions is a binomial test to determine if the number of successes in a large sample is significantly different than an expected null (McClave, Benson and Sincich, 1998: 345). If the supply chain reengineering had no effect on the demand levels and the safety stock, then the percentage of change would be expected to be close to zero. This is due to the probability of decrease or no increase in the variables being the null, meaning there would have been no significant change from 1994 to 1999. Throughout this thesis the research will conduct two tests of assumptions to validate the

use of this test: first, the test must be a binomial experiment, and second the sample size must be large enough that the sample approximates normality (347).

Given the nature of the previously stated null hypothesis and the binomial formatting of the data, the experiment is a binomial experiment. An established heuristic for testing the normal approximation to the binomial distribution is to require the sample size * samples probability of success (n*p) and the sample size * 1-probability of success (n*(1-p)) to both be greater than 5 (Clarke and Cooke, 1978: 211). The supply chain of the demand revealed that the supply chain demand sample is large enough to approximate normality. Because the probability of success is 28/33 and the sample size is 33, the resulting n*p equals 28 and the n*(1-p) equals 5.

The assumptions for the safety stock, however, were not met. Again, the experiment was a binomial experiment, but the heuristic suggested by Clarke and Cooke, 1978, is not met (n*p = 17, n*(1-p)=1). As a result the safety stock will not be subject to a formal test of hypothesis but will be simply analyzed qualitatively. The discussion of these two inventory measure tests (demand and safety levels), the evaluation of the differences in the flow of information and goods throughout the supply chain, and the exploration of alliances with suppliers will be used to examine the supply chain structure.

Second, Hammer (1990: 107) recommends that "we must challenge old assumptions and shed the old rules that made the business underperform in the first place." This qualitative analysis will attempt to show that the policy changes from 1994 to 1999 challenge old assumptions concerning hazardous materials. It will also attempt to show a

change in the business strategies as reviewing documents that changed business practices during the reengineering time period.

A final defining characteristic of reengineering found in the literature was that reengineering was done using information technology as the backbone of the restructuring (Orman, 98: King and Phumpiu, 96). To explore this aspect of reengineering, this thesis looked at the role information technology has played in the restructuring of the Hazardous Materials Pharmacy Program and asked whether or not information technology has restructured the supply chain. This information was analyzed both by inspection of the structure and by reviewing policy relating to information technology in HazMarts. Finally, by considering the information presented concerning the three major business process reengineering assumptions, it may be shown that a reengineering has been done on this supply chain.

3.3 Hypothesis Two

Hypothesis two: Reengineering of the hazardous materials supply chain reduced the amount of hazardous waste the Air Force produced.

After determination of reengineering, it is necessary to next test the second hypothesis. The intent of this thesis was to show that reengineering a supply chain can not only save money, but can also reduce levels of hazardous waste. The next step in this thesis is to determine whether or not waste resulting from expired HazMat has declined. Short shelf lives of hazardous materials are often necessary in working with aircraft to ensure that the materials still contained their necessary properties to function correctly on

the aircraft (DLAM 4140.2, chapter 1, section IV). Having a shelf life, however, limits the amount of time that many hazardous materials can actually stay on the shelf without generating hazardous waste when the HazMat expires.

3.3.1 Data Collection and Preparation. Empirical data was obtained in several different ways from different agencies to test this hypothesis. Initially, 45 national stock numbers (NSN) were randomly selected from McChord Air Force Base's Hazardous Materials stock listing. McChord Air Force Base was initially thought to be one of the two bases that would be studied in this supply chain. However, due to the lack of 1994 historical data on specific line numbers at McChord AFB, Charleston AFB and Dover AFB were used instead. This led to the original 45 national stock numbers being used from McChord data supplying 22 data sets from Dover AFB, 27 data sets at Charleston AFB and 36 data sets at DLA. All data was obtained from the May 1999 Standard Base Supply System database at base levels, from the Defense Logistics Agency Defense Logistics Information Services database at Richmond, and from the AFLMA historical database.

The percentage of HazMat inventory that could be expected to turn to waste while on hand was then computed using McChord AFB historical information from 1995-1998. The expected waste as a percentage of inventory was found by analyzing the three years of monthly data to derive a mean and a 95% confidence interval. The waste data showed a mean amount of waste due expected to expire as inventory to be 2.2214% with a 95% confidence interval of plus or minus 1.4079% of Hazard Materials inventory (appendix

G). The actual number used in this research to compute the HazMat expected to shelf-life expire was 2.2214%.

This percentage was then computed against on hand inventories for the given NSNs in the supply chain. The data was transformed for analysis and to standardize the percentage of change to simplify comparison. The transformation formula used was $(1994_{\text{waste}} - 1999_{\text{waste}}) / 1994_{\text{waste}}$ as this gave a percentage (negative or positive) of change in the expected waste from 1999 to 1994.

Data analysis was then accomplished to determine if any of the following data would be eliminated due to mathematical inconsistencies. All data points were discarded that had a 1994 expected waste of zero, due to not being able to divide by zero. In the waste data, 4 data points were discarded for a dataset number of 32. The data was then again transformed to represent binomial (success/failure) data. Any number greater than zero showed a greater amount of waste in 1994 than in 1999 and was given a value of one as a success. Zero and negative values were coded as a zero denoting a failure.

The expected waste for 1994 was then tested for decline in 1999 by using the proportions test. The test of proportions is a binomial test to determine if the number of successes in a large sample is significantly different than an expected null (McClave, et al. 1998: 345). If the supply chain reengineering had no effect on the expected waste, then the percentage of change would be equal to or less than zero percent, meaning there would have been no significant change between 1994 and 1999.

The proportion test's assumptions were validated to use this test of hypothesis on the waste data. First, the test of waste was shown to be a binomial experiment. Given the

nature of the null hypothesis and the formatting of the data so that any positive number of the 1994_{waste}-$1999_{waste}/1994_{waste}$ is a success, a binomial experiment has been established. Second, the sample size is large enough that the sample approximates normality. The test of normality shows that n*p = 22 and that n*(p-1) = 10 using the working rule suggested by Clarke and Cooke, 1978. Further analysis of the data also looks at the standard deviation of the proportions, in all cases of computing the standard deviation a probability of .5 and q = (1-p) was used to give the most conservative estimate of the standard deviation. Standard Deviation = $\sqrt{\frac{P_o * Q_o}{N}}$ (McClave, et al. 1998: 347).

3.3.2 ***Method of Analysis.*** Due to the data meeting the necessary assumptions, the proportions test was used for the analysis of the waste data. The test statistic used to analyze the data was the Z statistic given by the formula $P^{hat} - P_o / \sigma_{phat}$. P^{hat} is the actual calculation of the successes divided by the total number of trials. In this test of hypothesis, P^{hat} is the number of stock numbers with a transformed number greater than zero, divided by the total number of transformed numbers retained in the experiment. P_o is the assumed null percentage, or zero in this experiment, and σ_{phat} was the standard deviation previously discussed. The Z statistic was further interpreted by finding the probability of Z, commonly called a p-value. The p-value was calculated by subtracting the probability of Z on a standard normal distribution from 1. The Z probability was found by using the Zinverse function of the calculated Z value in the Statistix version 1 software (1996). A p-value less than the alpha of this experiment (.05) is considered sufficient evidence to reject the experiment's null hypothesis (McClave et al. 1998: 347).

The Z value and P-value were calculated using the Microsoft Excel 97 software worksheet and formulas from McClave, et al. (1998: 347). The test of hypothesis the integrated waste in the supply chain were:

$$H_o\text{: P(successes)} \leq 0$$
$$H_a\text{: P(successes)} > 0$$

The value statement was if the P-value < .05 reject the null with a level of significance of 95%. The results of these tests and the conclusions drawn from the results are discussed in chapter four of this thesis.

3.4 Hypothesis Three

Hypothesis three: The reengineering of the Air Force Hazardous Materials Supply Chain decreased the costs associated with the HazMat inventory.

The final test of hypothesis was done to discover whether or not reengineering the supply chain of hazardous materials did indeed reduce the cost associated with these hazardous materials. The specific cost examined was holding costs; other inventory-related costs were omitted for various reasons.

For instance, since the policy regarding ordering (an Economic Order Quantity is still in use) has not changed since 1994 (AFI 23-110: DLAM 4140.2), the ordering costs will not have changed, except as a function of demand. The thesis did show a significant decline in demand, meaning fewer orders were accomplished. However, this is all a result of a smaller inventory and the increased scrutiny surrounding hazardous material consumption. In addition, neither DLA nor the Air Force has altered the ordering cost

during the time span discussed in this thesis. As a result, it makes little sense to use ordering cost as a variable in this analysis.

Additionally, since the ordering policy has not changed, only changes in the lot size would effect a change in the transportation of these materials. It is notable, however, that the transportation of hazardous materials has been increasingly regulated and the extra costs placed on the transportation of HazMat is now higher for most HazMat in 1999.

However, in order to analyze this complex supply chain, it was necessary to assume that the inventory in 1994, if in effect today, would still have these regulations imposed upon it effecting similar transportation costs (49 U. S. C., Chapter 51). Again, the only changes in transportation costs would then be the lower costs assumed due to the decline in demand.

The holding costs remained as the sole indicator of cost savings. Although they may not have given the complete cost savings, they gave an accurate portrayal of whether or not the HMMP did indeed save money. Because the holding cost is often the largest of all logistics costs (Lambert and Stock, 1993: 364) it is a good indicator of cost savings in inventory. Since holding costs subsume the capital investment lost by the purchase (Lambert and Stock, 1993: 368) of inventory, purchase costs and unit costs were used in this analysis, but only as a function of holding costs.

3.4.1 Data Collection and Preparation. The method used for finding if holding costs were less in 1999 than in 1994 was to compare the holding costs from 1999 to those of 1994 using the test of proportions. Since the average inventory was unavailable

through data sources, the use of on hand inventory was used as a "snapshot" of average inventory. Even though this use of on hand inventory made the findings less generalizable, it accomplishes the task of attempting to quantify the inventory of a supply chain. The limitations inherent with using this cross-section are discussed further in chapter five.

Since the emphasis on supply chain reengineering is on total systems costs rather than on functional areas' costs, the thesis evaluated the integrated supply chain costs involved with the remaining 36 hazardous material line items. In order to derive total costs for the respective chains, each item's 1999 adjusted unit cost was multiplied by on-hand inventory at each point of the supply chain. This cost of inventory was individually multiplied by an average holding cost (Air Force Holding cost percentage, as given in AFI 23-110, Volume 2, Part 2, Chapter 19, is 15%), then the sum of the values for each line item was added together.

The unit costs for this analysis were scaled so that the 1994 unit costs were adjusted to 1999 values. This adjustment was accomplished by dividing the average Producer Price Index for Inorganic Chemical for 1998 by the PPI for inorganic chemicals in 1994 (Bureau of Labor Statistics, 1999). This percentage, 1.07, was then applied to 29 of the 36 unit prices from 1994 to derive their 1994 adjusted unit cost. Seven of the remaining stock numbers did not have their unit prices recorded in the 1994 historical records. As a result the 1999 unit prices were used for these national stock numbers under the assumption that the 1999 price was a reasonable estimate of the 1994 adjusted unit price. The data was then transformed to represent the percentage of change (positive or

negative) in holding cost from 1994 to 1999. The transformation formula used was ((On Hand * 1999 Adjusted Holding Cost) - 1999 Holding Cost)/ ((On Hand * 1999 Adjusted Holding Cost)).

3.4.2 Hypothesis Three Methods. The data was then again transformed to represent a binomial, success/failure, experiment. Any originally transformed percentage greater than zero showed a greater amount of waste in 1994 than in 1999 and was given a value of one as a success. All other percentages were considered a failure except those data points excluded due to the impossibility of division by zero.

The holding cost for the 1994 inventory was then tested against the 1999 inventory by using the proportion test. If the supply chain reengineering had no effect on the holding cost, then the percentage of change would again be expected to be zero.

The two proportion test assumptions are validated in this section. Both of these tests were necessary to establish the validity of the data as well as to establish the validity of using the test of proportions statistic (McClave et al. 1998: 346). First, the test was shown to be a binomial experiment. Given the nature of the null hypothesis and the formatting of the data so that any positive number of the 1994_{cost}-1999_{cost}/1994_{cost} is a success and a negative number a failure, a binomial experiment has been established. Second, the sample size is large enough that the sample approximates normality. The test of normality concluded that the both n*p and n*p-1 (21 and 11 respectively) were greater than 5.

Due to the data and experiment meeting the assumptions, the proportions test was used for the analysis of the waste data. Once again, the test statistic used to analyze the data was the Z statistic given by the formula $P^{hat} - P_o / \sigma_{phat}$. P^{hat} is the actual calculation of the successes divided by the total number of trials. In this test of hypothesis, P^{hat} is the number of stock numbers with a transformed number greater than zero, divided by the total number of transformed numbers retained in the experiment. P_o is the assumed null percentage, or zero in this experiment, and σ_{phat} was the standard deviation, again using p=.5 as a conservative measure, given by the formula = $\sqrt{\frac{P_o * Q_o}{N}}$ (McClave, et al. 1998: 347).

The Z statistic was further interpreted by finding the p-value. The p-value was calculated by subtracting the probability of Z, again using the Zinverse function of the calculated Z value using Statistix, from 1. A p-value less than the alpha of this experiment (.05) would be sufficient evidence to reject the experiment's null hypothesis (McClave et al. 1998: 347).

The Z value and P-value were calculated using the Microsoft Excel 97 software worksheet and formulas from McClave, et al. (1998: 347). The test of hypothesis for the integrated cost in the supply chain were:

$$H_o\text{: P(successes)} \leq 0$$
$$H_a\text{: P(successes)} > 0$$

The value statement was if the P-value < .05 reject the null with a level of significance of 95%. The results of these tests and the conclusions drawn from the results are discussed in chapter four of this thesis.

IV. ANALYSIS AND RESULTS

The preparation of the data and outlining of methods has led to the individual tests of the hypotheses. The first hypothesis will introduce the DoD's strategic changes (the management changes) from the implementation of EO 12856 to 1999. Then, the first hypothesis will explore operational changes (business process changes) as evidenced through correspondence and policy statement. Following analysis of the operational changes, an inspection of the structural changes of the supply chains will be discussed. Finally, qualitative analysis to reconcile the reengineering parameters discussed in the literature will be argued.

The second hypothesis will test the difference of expected waste generated by the 1994 and the 1999 supply chain. The research will then explain the context surrounding the results of this experiment. Finally, the third hypothesis will test the integrated cost data and discuss its significance.

4.1 Hypothesis One

Hypothesis one: The hazardous materials pharmacy program reengineered the Air Force's supply chain of Hazardous Materials.

This section will determine if the hazardous material supply chain was reengineered. Since supply chains consists of management components, business processes, and structure (Cooper, Lambert and Pagh, 1997) each topic will be discussed in this section. The qualitative nature of this section is due to the type of data being reviewed and the type of research being initiated.

4.1.1 Strategy. Strategy is necessary to discuss in reengineering because it represents the anticipated structure of the business and the focus of the company (Griffin, 1996: 332 and 202). By reviewing the course the Department of Defense and the Air Force have stated, the strategic part of the supply chain was revealed.

In addition to the previous literature review there are several memos and documents that outline the Department of Defense's strategic commitment to P2. For instance, in the Secretary of Defense's Annual Defense Report 1996, the Secretary of Defense proclaimed, "The Department of Defense is strongly committed to a P2 program that affects every aspect of its activities.... It also reduces future compliance costs. Only by eliminating hazardous materials or those processes generating hazardous by-products can overall costs be reduced" (DOD 1996: Ch 15, npg).

A more recent, 1998, report stated "DOD's emphasis is on reducing costs and meeting existing or emerging compliance requirements by preventing pollution at the source. At the heart of these integration efforts are sound business practices" (DOD 1998: Ch 18, npg).

Finally, the Secretary of the Air Force in 1995, Sheila Widnall, wrote a memo entitled Air Force P2 Strategy clarifying the Air Force's P2 strategy. She wrote that to update its strategy the Air Force will minimize the use of hazardous materials in all of its operations through business partnerships and improved business practices (Widnall, 1995).

P2, however, was not the only strategic change that was implemented during these years; logistics strategies were also changed. Again in the annual report to the President,

the Secretary of Defense reported "Each military department and the Defense Logistics Agency are reducing supply inventories by improving equipment reliability, reducing logistics response times, acquisition lead times, and other cycle times. They are also reducing supply inventories by improving their requirements processes, by selective outsourcing of weapon system support and other functions, by reducing retention levels in some cases, by having stock shipped directly to the end user by the vendor, and by examining more closely what is being held on the shelf as opposed to disposing of inventory being held in support of weapon systems no longer in use by U.S. forces and those of U.S. allies. The Department continues to draw down supply inventories to match reductions in force structure" (DOD 1998: Ch 18, npg).

The implementation of information technology to accomplish much of this change was also documented in this report as evidenced by a 1998-acquisition reform goal. Goal seven states "Decrease paper transactions by 50 percent through electronic commerce and electronic data interchange" (DOD 1998: Ch 18, npg). It is obvious from this review that these documents reveal that the management level of business process reengineering was obviously changed.

4.1.2 Logistics and Information. The logistics and information parts of reengineering a supply chain would identify those parts of the supply chain at the business process level. Additional consideration to the literature review is offered here to highlight actual business processes that have been reengineered. Good operational implementation of environmental strategy is very important as it allows companies to

gain all possible benefits from its implementation. (Epstein, 1996), so this part of the analysis looked at the operational implementation of the hazardous materials pharmacy.

Of utmost importance at the retail level of this supply chain was the release of Air Force Instruction 32-7086 (August 1997), which specifically directs the management of hazardous materials. Additionally, a recently released Air Force Joint Manual (AFJMAN 23-209: 1999) directs the storage and handling of hazardous materials for Air Force units when working in a joint endeavor with other military services.

The new policy does not, however, tell the complete story of the reengineering effort for actual changes that had been made. The Government Services Agency is perhaps the most reengineered of all the links in this report. Previous to the business process changes, government services agency ran their business like most distribution centers: they held inventories based on forecasts and sold to retailers when government computer systems or individuals ordered from them. Since then, however, they have turned into more of a virtual organization: they carry very little inventory and stock almost no hazardous materials. They have accomplished this reduction through using the Internet to allow customers to order through them, but directly from suppliers. Their website, http://pub.fss.gsa.gov/, allows consumers to order their hazardous materials directly from a vendor of the consumer's choice while fulfilling federal acquisition laws regarding competitive pricing. They also have implemented concerted research on return to vendor programs and other reverse logistics systems. In short, the government services agency, a wholesale link in this supply chain, has reengineered the logistics at the operational level using information technology (Shobert, 1999).

4.1.3 Structure. The structure of logistics in a supply chain is very important as it reveals the ability of the supply chain to gain control of inventory and service (Lee, 1992: 158). The organizational structure also allows people within the chain to understand the business transformation (Cheyunski and Millard, 1998).

A visual inspection of the hazardous material supply chain reveals significant changes in both service and inventory over the last five years. (Compare Figure 1 to figure 2 and figure 3). An important change in the structure of the supply chain is that implemented by a government credit card, the International Merchant Purchase Authorization Card or IMPAC, used to purchase relatively low cost items from local vendors. The IMPAC card has allowed consumers vendor direct delivery with no retail level storage on base. The government services agency restructuring previously discussed also offers consumers the benefit of vendor direct delivery by using this credit card.

However, the IMPAC card may have actually increased the cost of the Department of Defense supply chain by increasing the ordering costs and shipping costs to leverage the lower inventory levels. These cost tradeoffs are discussed in chapter five as potential future research.

Although not implicitly a part of the restructuring, the partnering relationships in this supply chain are noteworthy. Because it has been federally regulated, the purchasing methods used in the Department of Defense rely on specified length contracts won in free and open competition to provide most supplies to its agencies (Arnavas and Ruberry, 1994: 2-16). This practice is in contrast to older business practices of industry buying

from the least cost vendor whenever a lower cost vendor could be found. As previously discussed, these partnerships are a defining practice in most civilian supply chains and are evident in the supply chain of the United States Air Force. In addition, having more accurate demand data has allowed 1999 to be a leaner supply chain. The safety stock requirements have been reduced at the Defense Logistics Agency and the number of line items stocked at the base level HazMart has been significantly reduced. The structure of inventory and service within this supply chain has been altered.

Specifically, the safety stock once carried at DLA has been reduced and many GSA managed inventories have been eliminated completely (Appendix F and Appendix H). This reduction is due in large part to the better information being transmitted up from individual bases. Because unnecessary demand is no longer being translated up the supply chain, the necessity for holding safety stock has declined.

4.1.3.1 Decline of Demand Analysis. The thesis has presupposed that the 1999 supply chain more accurately defined demand by making the purchase of hazardous materials more difficult. This presumption, in turn, led to a resulting presumption that demand had declined. To test this presumption that demand declined a test of proportion, as discussed in chapter three, was used to evaluate whether or not it was probable that demand had declined. The difference was tested using the evaluation of the 1994 demand minus the 1999 demand divided by 1994 demand. This gave a percentage of change of from 1994 as compared to the demand level for 1994. The results are reported in Table 1.

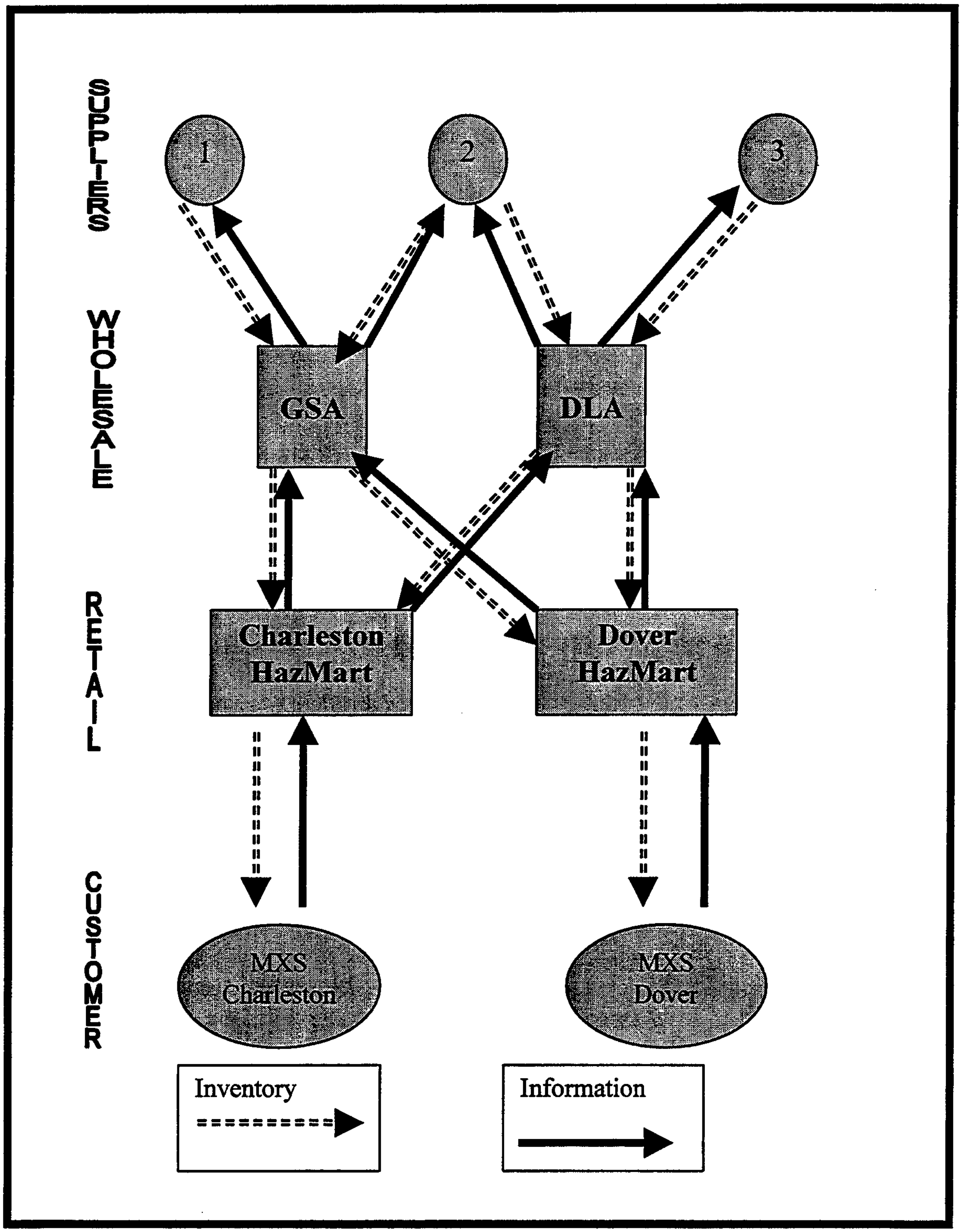

Figure 2. 1994 Hazardous Material Supply Chain Structure

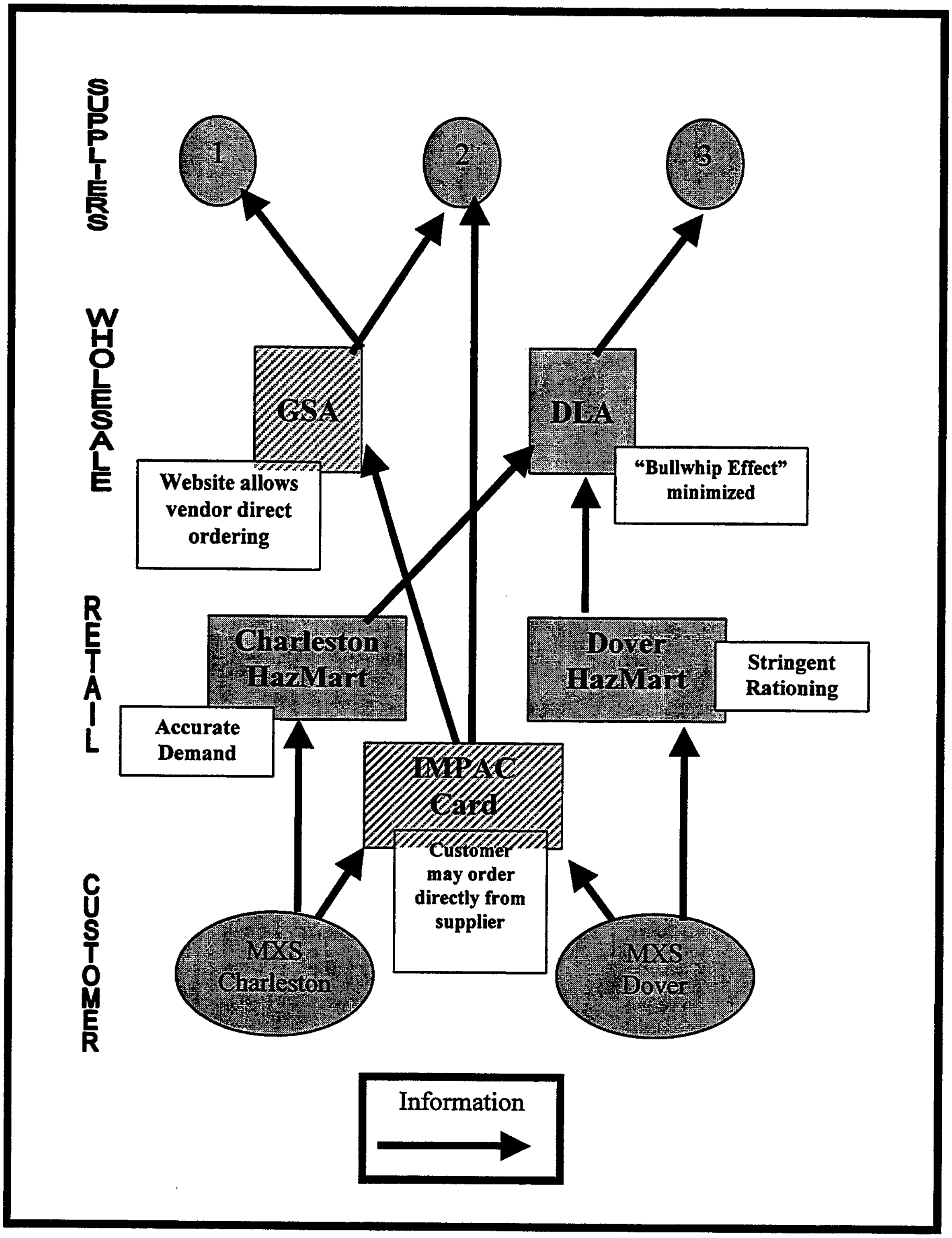

Figure 3. 1999 Hazardous Material Supply Chain Structure – Information

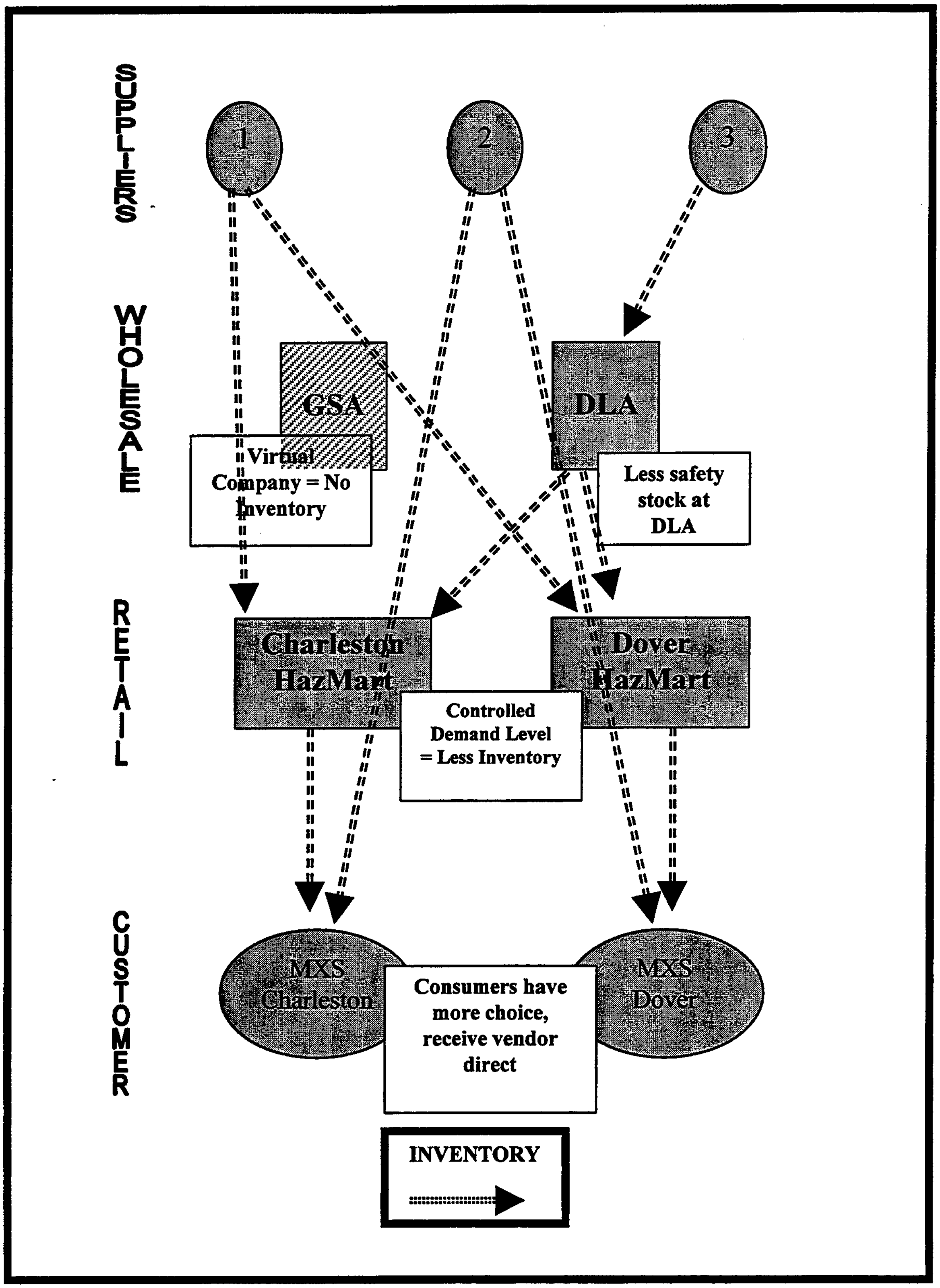

Figure 4. 1999 Hazardous Material Supply Chain Structure – Inventory

Table 1. Proportion Test for Demand

NULL HYPOTHESIS: $P \leq 0$ ALTERNATIVE HYP: $P > 0$	
Variable	**Demand**
n	*33*
$\sigma_{phat} = \mathrm{sqrt}(pq/n)$	**0.087038828**
$p^{hat} = {}^{Success}/_{n}$	**0.848484848**
$Z = p_{hat} - p_o / \sigma_{phat}$	**9.748348734**
P-Value (Z)	**< 1E-09**
$Z_{crit} =$	**1.64**

The results show that demand was decreased from 1994 to 1999. The can be seen due to the very small p value, less than 0.000000001, being less than .05. It appears that the reengineering throughout the supply chain to reduce demand was effective. The decline in demand bolsters the idea that reengineering was done.

4.1.3.2 Decline of Safety Stock. The thesis has also presupposed that the more accurate demand also reduced the wholesale, safety stock requirement. Since no test of hypothesis could be done to test this assumption, a simple qualitative analysis was done. It is obvious that by transforming the data of the DLA safety stock into a binomial experiment there are many more successes than failures (17 of 18 data points were successes). This would lead one to believe that the safety stock at DLA has been significantly reduced. It also of note that GSA no longer needs to carry a safety stock as a result of vendor direct deliveries and their efforts towards becoming a virtual organization. The result is that the safety stock appears to have been significantly

reengineered. This finding lends support for the idea that the structure of inventory within this supply chain has been reshaped.

4.1.3.3 GSA Restructuring. In addition to these two tests suggesting links in the supply chain have been restructured, is the fact that the GSA has reorganized itself into a virtual organization by using available information technology. The technology has also contributed to more stringent rationing of HazMat to the customers and more accurate demand information at the retail level making forecasting more accurate. At the DLA level, again, the lack of distortion in demand has minimized "the bullwhip effect" previously discussed.

The overall structure appears to have changed from a one for one swap of information for inventory in the 1994 supply chain, to information allowing the postponement of logistics functions in the 1999 supply chain. Overall the decline in demand, the lower safety stocks, the addition of the IMPAC card and the GSA restructuring support the idea that the structure has been reengineered.

4.2 Hypothesis Two

Hypothesis two: Reengineering of the hazardous materials supply chain reduced the amount of hazardous waste the Air Force produced.

The establishment that the waste in this supply chain has been reduced is vital to establishing supply chain management as a P2 initiative when used in HazMat inventories. The following analysis of the hazardous waste data attempted to establish this hypothesis.

4.2.1 Waste Analysis. The finding that waste is lower in 1999 than it was in 1994 would support the hypothesis that reengineering the supply chain has reduced the waste in the supply chain. Since an integrated supply chain best represents the supply chain philosophy, the integrated waste was tested. This test was necessary because supply chain management attempts to look at cost savings from a systemic point of view rather than look at just at the links of the supply chain. A test of proportions was run on the aggregated waste from DLA, Charleston AFB and Dover AFB of the 32 NSNs in the sample to see if waste had actually declined.

The difference was tested using the evaluation of the 1994 expected waste minus the 1999 expected waste divided by the 1994 expected waste. This gave a percentage of change of total waste as compared to 1994 waste. Table 2 reports the results.

Table 2. Proportion Test for Waste

NULL HYPOTHESIS: $P \leq 0$ ALTERNATIVE HYP: $P > 0$	
Variable	**Waste**
n	32
$\sigma_{phat} = \text{sqrt}(pq/n)$	0.088388348
$p^{hat} = {}^{Success}/_{n}$	0.6875
$Z = p_{hat} - p_o / \sigma_{phat}$	7.778174593
P-Value (Z)	< 1E-09
$Z_{crit} =$	1.64

The results show that hazardous waste was decreased from 1994 to 1999. This can be seen due to the very small p value, less than 0.0000000001, being less than .05. It

appears that the reengineering effort has indeed been successful at reducing the hazardous waste in this supply chain.

4.2.2 Context. The results found that waste in the entire supply chain has significantly decreased with the change in the supply chain. It is obvious from these results that supply chain reengineering reduced the hazardous waste in the supply chain. The source reduction of hazardous waste is by definition P2. These tests confirmed that SCM did indeed lead to a reduction in the expected hazardous waste in this supply chain, and these findings establish that supply chain reengineering can be a P2 initiative.

4.3 Hypothesis Three

Hypothesis three: The reengineering of the Air Force Hazardous Materials Supply Chain decreased the costs associated with the HazMat inventory

The reduction of waste in this chain leads to the final test of hypothesis. Hypothesis three attempts to establish that not only can supply chain management be used to prevent pollution, but it can also be used in the same chain to reduce costs. It has been well established that SCM is effective at saving costs in a supply chain, but SCM has never been shown to reduce both hazardous waste and cost. The following analysis of the data tests this relationship.

4.3.1 Data Analysis. The data was analyzed using the excel software to discover if the percent difference between the 1994 and the 1999 data was in fact greater than zero.

A comparison of the percent change from 1994 to 1999 was accomplished with the generated values summarized in Table 3.

Table 3. Proportion Test for Holding Cost

NULL HYPOTHESIS: $P \leq 0$ ALTERNATIVE HYP: $P > 0$	
Variable	**Holding Cost**
n	32
$\sigma_{phat} = \text{sqrt}(pq/n)$	0.088388348
$p^{hat} = {}^{Success}/_{n}$	0.65625
$Z = p_{hat} - P_o / \sigma_{phat}$	7.424621202
P-Value (Z)	< 1E-09
$Z_{trit} =$	1.64

4.3.2 Significance of Results. These results show two specific things. The holding cost numbers show that the holding costs representing 1994 are greater than the holding costs representing 1999. Since the p value, >0.00000001, is less than .05 the null hypothesis that the change was equal was rejected and the alternate hypothesis that the percentage of difference was positive was supported. From this analysis it appears that the holding cost has decreased from 1994 to 1999 in this supply chain.. These tests and the literature reviewed support the finding that costs have been reduced. Thus, the third hypothesis in this thesis is also supported. These results show that the supply chain was reengineered, pollution prevention was achieved and cost was reduced. In short, the three hypotheses were all supported, lending credence to the thesis.

However, this thesis does not infer that the Air Force HazMat supply chain is currently optimized to reduce waste and cost. Business practices may be further

reengineered to make this chain more efficient. For instance, the Air Force continues to use an economic order quantity to order its HazMat (AFI 23-110, 1997: 2-2-19-1a), when other inventory models may be more appropriate with this short-lived product (Karawarwala and Matsuo, 1996). Additionally, the EOQ model assumes that demand is known, uniform and continuous (Tersine, 1994: 205), however, this thesis has shown that the Air Force demand of hazardous materials is actually in decline. An inventory model that uses a declining demand may be more appropriate. Finally, the influence of information technology in this supply chain appears to have been under appreciated. This may be due to computer system currently in use at the HazMart that do not interface with either the Air Force computer system or the DLA computer system. An integration of the different information systems may lead to enhanced inventory control. In the end, it remains that supply chain management can now be looked at as a technique to both preclude pollution and reduce costs.

V. DISCUSSION

The results of this exploratory research have several implications in the business world. These implication include the use of supply chain reengineering to accomplish P2, optimizing supply chains to leverage waste against cost, and using inventory location to place hazardous waste in the least cost environment. These findings are limited by some confounds that were encountered in this thesis due to a small sample size, incomplete data sets and no previous research. However, follow on research to this exploratory study is extensive and expansive.

5.1 Implications

This thesis had already established in the literature review that supply chain management is an effective cost management practice (Arntzen and others, 1995: Lee and Khumawala, unpublished). With the conclusion of the second test of hypothesis it is now established that reengineering a HazMat supply chain can reduce the HazMat waste. Although in this particular supply chain both cost and waste were reduced, it appears plausible in the light of this research that optimization of a hazardous material supply chain could lead to a system that further reduces both waste and cost.

One of the real contributions of this research was that it broadened the use of supply chain management to include the management of waste. The literature review showed that logistics managers are in a position to influence environmental issues (Browne and Allen, 1997), this experiment substantiated that claim. Furthermore, the refocus of

supply chain management towards environmental issues could broaden the job descriptions of logistics managers to include some P2 duties.

Finally, the research establishes some Air Force business practices that may be suboptimizing this supply chain. By identifying these practices and doing further research into their total systems effect, more environmental and cost effective inventory practices can be realized.

5.2 Limitations

The results of this research must be qualified by identifying limitations of this research. It is necessary to understand that generally, total cost tradeoffs within the supply chain are explored in SCM research, however, the only figure used to estimate costs in this thesis were inventory holding costs. The lack of total costs or even estimates of costs limited the scope of analysis to just the cost of having inventory at certain locations. Because these costs were not captured, some functional silos of the supply chain appear to have been ignored. However, due to the relatively few changes to transportation and ordering costs in this particular chain, holding costs provide an effective estimate of total costs. Nevertheless, future studies evaluating costs of the supply chain should make further attempts to capture the total systems costs.

Additionally, the cross-sectional nature of the data limited it ability to accurately describe the average inventory. Since the on-hand inventories were compared at two points in time, anomalies were found in outlier analysis (the three eliminated data points) that average inventories may have smoothed. Additionally, the cross section may have

included information that was not an accurate picture of inventory. The cross-sectional nature of this study could be alleviated by using either average inventories in the future or by using many cross sectional points to explore the supply chain.

A further limitation of this research was the lack of study on the amount of hazardous materials currently contributing to the Air Force waste stream. The waste portion of this study is further limited by the application of McChord Air Force Base waste data to the entire supply chain. Since, most waste data was reported in pounds, and most supply systems recorded line items or a unit, deriving an actual amount of hazardous waste due to a HazMat inventory was difficult. Due to the lack of information into how many materials go to waste due to shelf life expiration, the McChord data was sufficient.

The initial use of the McChord data also limited the size of the sample for this study. Originally 47 stock numbers were chosen as a sample, all with current demands. However, due to different requirements at Dover and Charleston, the sample size was diminished. This smaller sample size led to a decrease in the power of the experiment. However, due to the strength of the tests used and the randomly selected sample, the sample appeared to represent the population.

An additional limitation in the research was the lack of analyzing the complete chain of supply. Because the level above the wholesaler had over 40 separate suppliers for the sample size of 33 national stock numbers, each sample would have had to have been analyzed to reach the beginning point of this supply chain. Further research could expand this supply chain to include the entire chain of supply, which was beyond the scope of this study.

Final limitations were the lack of some historical data regarding these hazardous materials. For instance, seven unit prices were missing on the 1994 DLA data so 1999 prices were used in those instances. Other missing information in the data led to some outlying data sets later being eliminated.

5.3 Follow-on Studies

Because this research was exploratory, many follow-up studies to this thesis are suggested. Most of the initial follow-on studies are the result of inconsistencies between theory and application. However, some additional research questions were suggested simply by serendipity during the research process.

It has already been suggested that this supply chain could be optimized, however, it would be noteworthy to see what inventory policy would result in the least cost and least wasteful supply chain. This could be accomplished by using information discussed in this thesis to run a simulation study to compare the effects of different inventory policies on the two variables. The results might be a more in depth look at how to best optimize this supply chain, it could also potentially save the DoD money due to the decreased hazardous wastes and lower inventory costs.

Another area of research may delve into the use of global supply chains of hazardous materials and logistics postponement. The application of this research could be to find what country in the global environment has the lowest hazardous waste disposal costs and use that place utility to postpone inventory. In a supply chain composed of mostly hazardous materials, like the chemical manufacturing industry, this would push hazardous

waste costs to the least cost environment. Doing this sort of research may find a value-adding function of location where one did not previously exist.

It may also be worthwhile to devote follow up study to the benchmarking of other short life cycle products into P2 research. For instance, one could use the recent supply chain initiative called "the national consumer response initiative" as a benchmark in how to use postponement to reduce waste. This would allow other industries to benchmark the study of the grocery store attempts to reach consumers with produce as quickly as possible, yet have as little waste as possible. By doing an analysis of their results, applications into the management of hazardous materials might be applied to reduce waste.

Another area of needed research in the military is a cost analysis of IMPAC card use. Because the IMPAC card was brought into the Air Force as a cost saving measure, it would be good business practice to find what the return on investment has been for the card. If research could find the total cost, ordering costs, transport costs, and loss of lot size discounts due to IMPAC card use it would be interesting to compare it to the estimated cost of the same demand using economic order quantity or other inventory models. It also might interesting to explore the influence the IMPAC card has had on inventory information systems within the DoD. For example, it may be shown that it has distorted forecasting information enough to actually be a detriment.

Hazardous materials also present substantial research opportunities to the Air Force as it appears that the DoD might underestimate the holding cost percentage of hazardous materials. Since most perishable items have an increasing and nonlinear holding cost

(Chaudhuri and Giri, 1997), it might prove helpful to calculate a more indicative holding cost for hazardous materials. Managers to make more rational decisions about outsourcing, inventory reduction and life cycle costs of HazMat could then use this different holding cost. Research could then suggest more effective inventory models to hold these goods.

Another inventory policy that could be investigated as a result of this thesis is to determine what value has been added to products bought through the Government Services Agency Advantage website. This could be multifaceted as the IMPAC of a virtual company and its effect on stock outs could be explored, as could total systems costs and labor costs. Costing the effects of this change using activity based costing as suggested by LaLonde and Pohlen, 1996 could prove enlightening.

A final research question that might prove fruitful would be to look at integrating all defense inventory information systems. By combining management functions, a more integrated supply chain perspective might be achieved. By reviewing the supply chain of all Department of Defense managed materials, it may prove cost effective to reduce the overall systems costs by putting supply chain managers in charge of chains rather than one link of the chain. This may lead to inventory policy dictated by the Defense Logistics Agency to optimize the supply chain of the Department of Defense.

5.4 Conclusion

The objectives of this thesis were to show that reengineering a supply chain could result in cost savings and reduce hazardous waste. The thesis actually showed that

aggregate waste was reduced by the Air Force supply chain, and suggested that the future optimization may allow for cost and waste minimization.

The effects of this thesis as exploratory research should help broaden the field of supply chain management to include application previously not researched. It may also provide good rationale to bring together the careers of logistics managers and environmental managers to take advantage of the pollution preventing aspects of logistics functions.

Appendix A - List of Acronyms

Acronym	Definition
AF	Air Force
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
DLA	Defense Logistics Agency
DoD	Department of Defense
EO	Executive Order
HazMart	Hazardous Materials Storage Facility
HazMat	Hazardous Materials
HMMP	Hazardous Materials Management Program
IMPAC	International Merchant Purchase Authorization Card
NSN	National Stock Number
P2	Pollution Prevention
SCM	Supply Chain Management

Appendix B - Charleston 1994 Data

	NSN (1994)	Loc	On Hand	Demand	Unit Cost	1999 Adjusted Cost	OH Inv Cost	OH Holding Cost
1	6135013511131	S9G	-	-	$ 4.58	$ 4.89	$ -	$ -
2	6810002271307	S9G	-	-	$ 41.83	$ 44.67	$ -	$ -
3	6810002388119	S9G	91	51	$ 4.43	$ 4.73	$ 430.52	$ 64.58
4	6810002499354	S9G	67	33	$ 3.13	$ 3.34	$ 223.96	$ 33.59
5	6810002646535	S9G	3	6	$ 4.10	$ 4.38	$ 13.14	$ 1.97
6	6810002812762	S9G	-	27	$ 23.76	$ 25.37	$ -	$ -
7	6810008161025						$ -	$ -
8	6850001053084	S9G	218	69	$ 11.32	$ 12.09	$ 2,635.41	$ 395.31
9	6850001817929	S9G	218	72	$ 5.20	$ 5.55	$ 1,210.61	$ 181.59
10	6850008411347	S9G	-	-	$ 3.71	$ 3.96	$ -	$ -
11	6850009845853						$ -	$ -
12	6850013980987						$ -	$ -
13	8010001818079	GSA	-	-	$ 28.80	$ 30.76	$ -	$ -
14	8010006169143	GSA	1	36	$ 1.54	$ 1.64	$ 1.64	$ 0.25
15	8010006169181	GSA	46	96	$ 1.58	$ 1.69	$ 77.62	$ 11.64
16	8010012299561						$ -	$ -
17	8030007838898	GSA	-	23	$ 14.69	$ 15.69	$ -	$ -
18	8030009369940	GSA	15	30	$ 8.08	$ 8.63	$ 129.43	$ 19.42
19	8030010462947						$ -	$ -
20	8030011840329	GSA	82	161	$ 11.88	$ 12.69	$ 1,040.34	$ 156.05
21	8040001236954	GSA	18	22	$ 29.61	$ 31.62	$ 569.19	$ 85.38
22	9150001178791	S9G	6	95	$ 1.52	$ 1.62	$ 9.74	$ 1.46
23	9150001181112						$ -	$ -
24	9150001497431	S9G	679	2,396	$ 2.42	$ 2.58	$ 1,754.81	$ 263.22
25	9150002234129	S9G	34	54	$ 6.74	$ 7.20	$ 244.73	$ 36.71
26	9150004506938	S9G	-	-	$ 4.00	$ 4.27	$ -	$ -
27	9150005297518						$ -	$ -
28	9150005437220	S9G	19	9	$ 19.70	$ 21.04	$ 399.73	$ 59.96
29	9150005987122	S9G	33	33	$ 1.47	$ 1.57	$ 51.81	$ 7.77
30	9150008345608						$ -	$ -
31	9150008893522	S9G	-	-	$ 3.53	$ 3.77	$ -	$ -
32	9150009354018						$ -	$ -
33	9150009857099	S9G	1,799	6,243	$ 3.43	$ 3.66	$ 6,589.77	$ 988.46
34	9150010355390						$ -	$ -
35	9150010872234						$ -	$ -
36	9150012602534	S9G	48	-	$ 3.32	$ 3.55	$ 170.19	$ 25.53

Appendix C - Dover 1994 Data

	NSN	Loc	On Hand	Demand	Unit Cost	1999 Adjusted Cost	Inv Cost	Holding Cost
1	6135013511131					$ -	$ -	$ -
2	6810002271307						$ -	$ -
3	6810002388119	S9G	98	75	$ 4.43	$ 4.73	$ 463.63	$ 69.54
4	6810002499354	S9G	123	123	$ 3.13	$ 3.34	$ 411.14	$ 61.67
5	6810002646535						$ -	$ -
6	6810002812762	S9G	32	25	$ 23.76	$ 25.37	$ 811.97	$ 121.80
7	6810008161025						$ -	$ -
8	6850001053084	S9G	20	22	$ 11.32	$ 12.09	$ 241.78	$ 36.27
9	6850001817929	S9G	47	-	$ 5.20	$ 5.55	$ 261.00	$ 39.15
10	6850008411347	S9G	-	27	$ 3.71	$ 3.96	$ -	$ -
11	6850009845853	S9G	-	5	$ 222.00	$ 237.08	$ -	$ -
12	6850013980987						$ -	$ -
13	8010001818079	GSA	28	24	$ 28.80	$ 30.76	$ 861.18	$ 129.18
14	8010006169143						$ -	$ -
15	8010006169181	GSA	69	165	$ 1.58	$ 1.69	$ 116.43	$ 17.46
16	8010012299561						$ -	$ -
17	8030007838898	GSA	-	-	$ 14.69	$ 15.69	$ -	$ -
18	8030009369940	GSA	42	16	$ 8.08	$ 8.63	$ 362.41	$ 54.36
19	8030010462947						$ -	$ -
20	8030011840329	GSA	48	97	$ 9.82	$ 10.49	$ 503.38	$ 75.51
21	8040001236954						$ -	$ -
22	9150001178791	S9G	30	-	$ 1.52	$ 1.62	$ 48.70	$ 7.30
23	9150001181112	S9G					$ -	$ -
24	9150001497431	S9G	778	331	$ 2.30	$ 2.46	$ 1,910.96	$ 286.64
25	9150002234129	S9G	8	7	$ 6.74	$ 7.20	$ 57.58	$ 8.64
26	9150004506938	S9G	25	9	$ 4.00	$ 4.27	$ 106.79	$ 16.02
27	9150005297518	S9G					$ -	$ -
28	9150005437220	S9G	58	24	$ 19.70	$ 21.04	$ 1,220.22	$ 183.03
29	9150005987122	S9G					$ -	$ -
30	9150008345608	S9G					$ -	$ -
31	9150008893522	S9G					$ -	$ -
32	9150009354018	S9G					$ -	$ -
33	9150009857099	S9G	3,171	1,293	$ 3.43	$ 3.66	$ 11,615.42	$ 1,742.31
34	9150010355390	S9G					$ -	$ -
35	9150010872234	S9G	85	59	$ 2.18	$ 2.33	$ 197.89	$ 29.68
36	9150012602534	S9G	132	26	$ 3.15	$ 3.36	$ 444.05	$ 66.61

Appendix D - DLA 1994 Data

	NSN	Loc	On Hand	Demand	ROP	ACQ Cost	1999 Adjusted	Safety Stock
1	6135013511131	S9G	21,569	114,564	26,313	$ 2.66	$ 2.84	5,775
2	6810002271307	S9G	499	487	388	$ 35.70	$ 38.13	150
3	6810002388119	S9G	9,255	13,928	6,355	$ 3.29	$ 3.29	1,434
4	6810002499354	S9G	23,905	225,251	29,604	$ 3.39	$ 3.62	10,253
5	6810002646535	S9G	561	1,508	1,584	$ 3.21	$ 3.43	790
6	6810002812762	S9G	10,374	9,717	5,776	$ 15.22	$ 16.25	1,158
7	6810008161025	S9G	594	703	364	$ 8.18	$ 8.18	152
8	6850001053084	S9G	95,533	14,773	18,749	$ 6.24	$ 6.24	9,272
9	6850001817929	S9G	26,023	110,923	545	$ 2.54	$ 2.71	7,158
10	6850008411347	S9G	1,724	6,349	2,493	$ 2.50	$ 2.67	857
11	6850009845853	S9G	1,605	2,001	1,710	$ 497.53	$ 497.53	-
12	6850013980987	GSA	-		-	$ -		-
13	8010001818079	GSA	-		-	$ -		-
14	8010006169143	GSA	-		-	$ -		-
15	8010006169181	GSA	-		-	$ -		-
16	8010012299561	GSA	-		-	$ -		-
17	8030007838898	GSA	-		-	$ -		-
18	8030009369940	GSA	-		-	$ -		-
19	8030010462947	GSA	-		-	$ -		-
20	8030011840329	GSA	-		-	$ -		-
21	8040001236954	GSA	-		-	$ -		-
22	9150001178791	S9G	9,924	68,183	89,510	$ 0.97	$ 1.04	22,849
23	9150001181112	S9G	107	225	102	$ 158.65	$ 169.43	25
24	9150001497431	S9G	102,498	347,289	170,721	$ 2.23	$ 2.38	12,473
25	9150002234129	S9G	1,041	4,695	3,169	$ 5.39	$ 5.39	828
26	9150004506938	S9G	3,718	1,173	1,517	$ 2.71	$ 2.71	-
27	9150005297518	S9G	75,302	9,174	9,717	$ 1.01	$ 1.01	4,364
28	9150005437220	S9G	3,189	2,011	1,778	$ 14.05	$ 15.00	-
29	9150005987122	S9G	1,037	6,286	6,880	$ 0.96	$ 1.03	458
30	9150008345608	S9G	592	1,057	434	$ 5.95	$ 6.35	-
31	9150008893522	S9G	21,033	23,432	34,076	$ 1.58	$ 1.69	11,534
32	9150009354018	S9G	7,139	13,399	13,978	$ 2.32	$ 2.48	-
33	9150009857099	S9G	113,310	1,461,619	458,766	$ 2.92	$ 3.12	-
34	9150010355390	S9G	9,231	3,400	3,742	$ 3.15	$ 3.36	-
35	9150010872234	S9G	5,892	3,025	5,805	$ 3.98	$ 3.98	1,655
36	9150012602534	S9G	28,841	55,578	18,112	$ 2.53	$ 2.70	-

Appendix E – Charleston 1999 Data

	NSN (1994)	Loc	On Hand	Demand	Unit Cost	Inv Cost	OH Holding Cost
1	6135013511131	S9G	107	110	$ 2.20	$ 235.40	$ 35.31
2	6810002271307	S9G	0			$ -	$ -
3	6810002388119	S9G	6	6	$ 4.55	$ 27.30	$ 4.10
4	6810002499354	S9G	0	0	$ 3.92	$ -	$ -
5	6810002646535	S9G	28	35	$ 5.61	$ 157.08	$ 23.56
6	6810002812762	S9G	0			$ -	$ -
7	6810008161025		0			$ -	$ -
8	6850001053084	S9G	0	0	$ 8.64	$ -	$ -
9	6850001817929	S9G	0			$ -	$ -
10	6850008411347	S9G	19	14	$ 3.94	$ 74.86	$ 11.23
11	6850009845853		0			$ -	$ -
12	6850013980987		4	4	$ 27.33	$ 109.32	$ 16.40
13	8010001818079	GSA	0			$ -	$ -
14	8010006169143	GSA	72	84	$ 1.90	$ 136.80	$ 20.52
15	8010006169181	GSA	0			$ -	$ -
16	8010012299561		0			$ -	$ -
17	8030007838898	GSA	6	9	$ 11.04	$ 66.24	$ 9.94
18	8030009369940	GSA	12	4	$ 103.76	$ 1,245.12	$ 186.77
19	8030010462947		70	158	$ 14.01	$ 980.70	$ 147.11
20	8030011840329	GSA	0	44	$ 44.34	$ -	$ -
21	8040001236954	GSA	17	18	$ 1.33	$ 22.61	$ 3.39
22	9150001178791	S9G	0			$ -	$ -
23	9150001181112		1557	2116	$ 3.04	$ 4,733.28	$ 709.99
24	9150001497431	S9G	18	17	$ 7.41	$ 133.38	$ 20.01
25	9150002234129	S9G	0			$ -	$ -
26	9150004506938	S9G	0			$ -	$ -
27	9150005297518	S9G	0	3	$ 20.70	$ -	$ -
28	9150005437220	S9G	0			$ -	$ -
29	9150005987122	S9G	0	0	$ 9.16	$ -	$ -
30	9150008345608	S9G	48	27	$ 2.26	$ 108.48	$ 16.27
31	9150008893522	S9G	0			$ -	$ -
32	9150009354018	S9G	2970	4032	$ 3.77	$ 11,196.90	$ 1,679.54
33	9150009857099	S9G	0			$ -	$ -
34	9150010355390		0			$ -	$ -
35	9150010872234	S9G	38	52	$ 4.41	$ 167.58	$ 25.14
36	9150012602534	S9G	3	9	$ 12.04	$ 36.12	$ 5.42

Appendix F - Dover 1999 Data

	NSN (1994)	Loc	On Hand	Demand	Unit Cost	Inv Cost	OH Holding Cost
1	6135013511131		0	106	$ 2.20	$ -	$ -
2	6810002271307	N/L	0	0	$ -	$ -	$ -
3	6810002388119	S9G	35	43	$ 4.55	$ 159.25	$ 23.89
4	6810002499354	S9G	47	37	$ 3.92	$ 184.24	$ 27.64
5	6810002646535	N/L	0	0	$ -	$ -	$ -
6	6810002812762	S9G	8	12	$ 18.35	$ 146.80	$ 22.02
7	6810008161025	N/L	0	0	$ -	$ -	$ -
8	6850001053084	N/L	0	0	$ -	$ -	$ -
9	6850001817929	S9G	0	0	$ 6.08	$ -	$ -
10	6850008411347	S9G	15	22	$ 3.94	$ 59.10	$ 8.87
11	6850009845853	N/L	0	0	$ -	$ -	$ -
12	6850013980987		11	18	$ 27.73	$ 305.03	$ 45.75
13	8010001818079	N/L	0	0	$ -	$ -	$ -
14	8010006169143		0	62	$ 1.90	$ -	$ -
15	8010006169181	N/L	0	0	$ -	$ -	$ -
16	8010012299561		14	27	$ 29.58	$ 414.12	$ 62.12
17	8030007838898	GSA	7	10	$ 11.04	$ 77.28	$ 11.59
18	8030009369940	N/L	0	0	$ -	$ -	$ -
19	8030010462947		73	117	$ 14.01	$ 1,022.73	$ 153.41
20	8030011840329	GSA	29	47	$ 44.34	$ 1,285.86	$ 192.88
21	8040001236954		0	0	$ 1.33	$ -	$ -
22	9150001178791	N/L	0	0	$ -	$ -	$ -
23	9150001181112	S9G	112	254	$ 2.13	$ 238.56	$ 35.78
24	9150001497431	S9G	5	0	$ 7.41	$ 37.05	$ 5.56
25	9150002234129	S9G	10	0	$ 3.88	$ 38.80	$ 5.82
26	9150004506938	N/L	0	0	$ -	$ -	$ -
27	9150005297518	S9G	1	16	$ 20.71	$ 20.71	$ 3.11
28	9150005437220	N/L	0	0	$ -	$ -	$ -
29	9150005987122	S9G	0	5	$ 9.16	$ -	$ -
30	9150008345608	S9G	0	6	$ 2.26	$ -	$ -
31	9150008893522	S9G	12	27	$ 4.84	$ 58.08	$ 8.71
32	9150009354018	S9G	322	498	$ 3.77	$ 1,213.94	$ 182.09
33	9150009857099	N/L	0	0	$ -	$ -	$ -
34	9150010355390	S9G	8	17	$ 3.51	$ 28.08	$ 4.21
35	9150010872234	S9G	0	0	$ 4.41	$ -	$ -
36	9150012602534	S9G	10	30	$ 5.04	$ 50.40	$ 7.56

Appendix G - DLA 1999 Data

	NSN	Loc	On Hand	Demand	ROP	ACQ Cost	Safety Stock
1	6135013511131	S9G	1,849	255,914	1,437	$ 1.91	2,486
2	6810002271307	S9G	286	232	120	$ 46.35	38
3	6810002388119	S9G	4,006	31,669	5,205	$ 3.29	2,486
4	6810002499354	S9G	21,207	32,230	12,897	$ 2.47	4,039
5	6810002646535	S9G	332	969	824	$ 3.21	546
6	6810002812762	S9G	270	6,559	113	$ 17.15	56
7	6810008161025	S9G	146	589	270	$ 8.18	63
8	6850001053084	S9G	42,003	7,253	6,188	$ 6.24	3,097
9	6850001817929	S9G	-	35,218	30,504	$ 4.39	9,052
10	6850008411347	S9G	5,564	6,147	3,920	$ 2.71	1,842
11	6850009845853	S9G	1,934	524	362	$ 497.53	95
12	6850013980987	S9G	9	770	1,036	$ 43.97	330
13	8010001818079	GSA	-	-	-	$ -	0
14	8010006169143	GSA	-	-	-	$ -	0
15	8010006169181	GSA	-	-	-	$ -	0
16	8010012299561	GSA	-	-	-	$ -	0
17	8030007838898	GSA	-	-	-	$ -	0
18	8030009369940	GSA	-	-	-	$ -	0
19	8030010462947	GSA	-	-	-	$ -	0
20	8030011840329	GSA	-	-	-	$ -	0
21	8040001236954	GSA	-	-	-	$ -	0
22	9150001178791	S9G	37,458	42,486	15,433	$ 0.93	12,155
23	9150001181112	S9G	161	19	40	$ 158.40	13
24	9150001497431	S9G	1,636	321,573	109,672	$ 1.99	23,003
25	9150002234129	S9G	5,680	3,777	3,109	$ 5.39	699
26	9150004506938	S9G	142	639	570	$ 2.71	364
27	9150005297518	S9G	20,516	7,952	5,149	$ 1.01	2,533
28	9150005437220	S9G	1,454	1,519	1,224	$ 14.60	501
29	9150005987122	S9G	3,250	409	266	$ 0.96	354
30	9150008345608	S9G	48	831	163	$ 6.73	0
31	9150008893522	S9G	36,116	15,666	24,917	$ 1.58	11,186
32	9150009354018	S9G	5,677	9,925	2,451	$ 3.38	772
33	9150009857099	S9G	518,542	1,106,379	595,483	$ 2.87	179,536
34	9150010355390	S9G	3,905	2,318	2,614	$ 3.15	1,608
35	9150010872234	S9G	4,627	2,111	1,968	$ 3.98	687
36	9150012602534	S9G	7,253	36,302	15,266	$ 3.12	3,847

Appendix H - McChord Waste Data

	JAN	FEB	MAR	APR	MAY	JUN
Expired 99	115	586	314			
Expired 98	0	7	94	42	137	201
Expired 97	10	0	0	8	23	52
Expired 96	138	122	175	68	322	47

Units 99	7559	2140	3866			
Units 98	5409	4322	4526	4048	3860	10386
Units 97	3207	4918	4876	5231	3850	3775
Units 96	4075	4886	4261	6066	4908	6350

Percentage waste

Expired 99	1.521%	27.383%	8.122%			
Expired 98	0.000%	0.162%	2.077%	1.038%	3.549%	1.935%
Expired 97	0.312%	0.000%	0.000%	0.153%	0.597%	1.377%
Expired 96	3.387%	2.497%	4.107%	1.121%	6.561%	0.740%

	JUL	AUG	SEP	OCT	NOV	DEC
Expired 99						
Expired 98	57	207	30	108	36	18
Expired 97	7	4	9	0	0	0
Expired 96	64	181	20	13	6	8

Units 99						
Units 98	3007	3865	6862	3076	3155	1951
Units 97	9807	10293	3294	2625	7121	3152
Units 96	3168	5969	4754	4552	4,684	4448

Percentage waste

Expired 99						
Expired 98	1.896%	5.356%	0.437%	3.511%	1.141%	0.923%
Expired 97	0.071%	0.039%	0.273%	0.000%	0.000%	0.000%
Expired 96	2.020%	3.032%	0.421%	0.286%	0.128%	0.180%

Appendix I – Electronic Mail Message From GSA

Lt Webb,

Hi. My name is Randy Schober, and I work as an Environmental Engineer with the General Services Administration here in Kansas City Missouri. I received a copy of your research question from the DLIS people. I have some information which may help.

First, GSA supports DoD and the entire Federal Government with streamlined ordering capabilities via the Internet. We have the "GSA Advantage" system whereby the customer enters our Internet database and can type in a specific National Stock Number or a specific product name, or a generic name for the product, or a military/federal/ or commercial specification number or part number or any piece of information that can be used to identify the item in our system and the system will find it and display a product description, the vendor, the price and shipping time, etc. They need only to place the order with their IMPAC card (if allowed to do so by their host base) and the manufacturer ships the order directly to the customer. This should help to reduce HM storage requirements as customers can order items and have an idea of when they are to be received, rather than having to order far in advance and store. Also, this should eliminate some waste from shelf life problems of old items.

Second, GSA has an electronic schedule system in the Internet where, similiar to GSA Advantage, the customer can select the company that they want, and review a price list of their products and make their purchase. There are some catches to this - the customer must review three price lists from customers and justify their selection. Justifiication need not be based on price alone however.

You can access these systems at the following website:

http://pub.fss.gsa.gov/

For the GSA Advantage domain, you should do the following:

Enter GSA Advantage
Where it says "sign in", hit "enter"
It will say "invalid sign-on". Just click where indicated

to continue

Type in your zip code

You are now in the system and can do example searches, etc.

These website above also gives you access to the electronic schedules;

For additional guidance on how to use each, the website has buttons which provide instructions.

Also, DLA and GSA Federal Supply Service is doing a lot to be environmentally responsive. We each handle certain commodities - GSA handles paints, sealants, adhesives, cleaners, just to name a few. (For a complete list of who handles what, just e-mail back your fax number and I will send it to you). We have an "environmental" page associated with our Federal Supply Service webpage. You can access it from the website above. Among some of the features of this page are cross reference tables created to allow the customer to find "suitable substitutes" for products for which they know the National Stock Number. The cross reference tables include: "High to Low VOC paints", "Multipurpose Adhesives", "1-1-1 Trichloroethylene substitutes, just to name a few.

We currently offer recycled latex paint on our GSA Advantage system. It is cheaper and helps federal facilities in meeting the objectives of Executive Order 13101 - Greening The Environmental Through env Friendly acquisition. I have attached an Excel spreadsheet whereby I list the national stock numbers of these recycled latex paints and the appropriate manufacturer and how much of that item GSA has sold since CY97. The GSA Advantage has all of these items available and gives descriptions of each, which vary by color or type/class of paint. Currently, here in my branch we are working with Industry to expand this program and list on our new paint orders whether the manufacturer would actually "take back" unused latex paint from Federal Customers as a service. We would then provide instructions for the customer to interface with the manufacturer to accomplish this turn in. This capability would expand our customers' ability to reduce hazardous waste generation or HM storage requirements.

The following two points of contact work at the two GSA supply depots in CONUS that handle our hazardous materials procured for Federal Agencies:

Mike Hight, mike.hight@gsa.gov, 609-499-4191, GSA Depot Burlington NJ
Bob Burnett, bob.burnett@gsa.gov, 209-946-6256, GSA Depot Stockton CA

They may be able to give you some information on on-hand stock levels, demand levels, safety stock levels, etc. from our perspective. On Wright-Patterson AFB, a good point of contact for base hazardous material stock would be John Banford, Wright-Patt HAZMART, 937-257-8015, ext 301 or john.banford@wrigem.wpafb.af.mil - I don't know if you have talked with him yet or not but he would be a great help, I think. I do not have a point of contact at McChord. For additional info on initiatives, however, the School of Civil Engineering and Services there at AFIT also should be able to help - Capt Jeff Rumrill - 5-5654, ext 3541.

Info on suppliers of various Haz Materials can be pulled right off of our GSA Advantage system. For DLA managed items, I would access their env products catalog or their website. I know you already have points of contact there.

I hope this info helps. My address, phone number etc are below. I used to teach at AFIT so that is how I am familiar with WPAFB and AFIT itself. Please call me if I can help further. I will do whatever I can to help.

Randy Schober
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GSA/FSS/6FET
1500 E Bannister Road, Building 6
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Vita

Lieutenant G. Scott Webb was born on August 14, 1968 in Caldwell, Idaho. He graduated from Marsing High School in Marsing, Idaho in 1986, being named the scholar athlete of the year. He entered undergraduate studies at Ricks Junior College in Rexburg Idaho where he graduated with an Associate of Arts and Sciences in Psychology in 1991. He then transferred to Albertson College of Idaho and in 1994 earned a Bachelor of Arts in Psychology.

After two years working as a criminal therapist in the Oregon State Prison system, Lt. Webb elected to join the Air Force. He received his commission through Officer Training School in January of 1996.

His first assignment was with the 62nd Supply Squadron at McChord Air Force Base as the Officer in Charge of the Hazardous Materials Pharmacy. After one year at the pharmacy, Lt. Webb was transferred to the combat support flight. In 1998, he entered the Graduate Inventory Management program, School of Logistics and Acquisition Management, Air Force Institute of Technology. Upon graduation he will be assigned to the Standard Systems Group at Gunter Annex in Montgomery Alabama.

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13. ABSTRACT (*Maximum 200 Words)*

Supply chain management was explored as a tool to prevent hazardous waste and reduce operating costs. Previous research had shown that pollution prevention measures were often costly and no expectation of cost savings could be realized. The reengineering of the Air Force hazardous material supply chain brought about by the Hazardous Material Pharmacy Program was tested to evaluate if hazardous waste had been precluded in this effort and if costs had also been avoided.

To date, no research had explored the use of supply chain management as a source reducer of hazardous waste. Consequently, little was known or understood of the effects that the use of this management system would have on preventing pollution. This thesis examined whether or not a reengineering was accomplished, if the reengineering resulted in reduced hazardous waste and if the reengineering reduced inventory costs. The results of the study provide evidence that supply chain reengineering occurred in the Air Force hazardous material supply chain, that the reengineering reduced hazardous waste, and that it precluded costs.

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3. **Please estimate** what this research would have cost in terms of manpower and dollars if it had been accomplished under contract or if it had been done in-house.

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5. Comments (Please feel free to use a separate sheet for more detailed answers and include it with this form):

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